



University of Hradec Králové
Faculty of Informatics and Management

Hradec Economic Days



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April 10–11, 2025
Hradec Králové, Czech Republic



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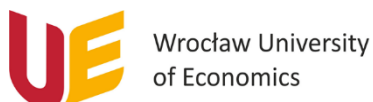
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Preface

Ladies and gentlemen, dear colleagues,

the Hradec Economic Days (HED) conference has been traditionally and continuously held since 2003. The 23rd HED took place April 10–11 in Hradec Králové. The University of Hradec Králové organized the conference in cooperation with the Wrocław University of Economics, the Cracow University of Economics.

The aim of the HED 2025 conference was to present the results of scientific research activities in the fields of economics, business economics, and management. We became a regular platform for meeting experts from such disciplines strengthening interdisciplinary relations and establishing personal contacts important for the submission of joint research projects and creating space for the presentation and publication of young members of an academic community. To fulfill these goals, we provided presentation sessions and a plenary session with foremostly keynote speakers:

- Luboš Komárek (Czech National Bank),
- Miloš Dendis (Dendis Capital),
- Tomas V. Michalek (STARTer Investment Partners).

To boost academia and practice interconnection, we also prepared discussion sessions:

- Good practice for academics with AI,
- Academic writing of higher impact factor journal article,
- Gamification integration in project management: afternoon,
- Methodology and software for writing a review.

Proceedings from the conference HED 2025 contain 29 contributions in English. The authors of the conference papers were academics and other professionals from the Czech Republic, Slovakia and Poland. I would like to warmly thank all participants of the HED conference for their contributions and favor. The final recognition belongs to the HED secretary assoc. prof. Ivan Soukal, editor dr. Martin Král, our organization, and scientific committee for their work. I would like to thank our co-funding our partners: OP JAK grant Budoucnost vzdělávání: Strategické řízení a rozvoj priorit Univerzity Hradec Králové, no. CZ.02.02.XX/00/23_022/0009008 and Hradec Králové region grant no. 25RGI02-0138.

Hradec Kralove, April 1, 2025

Assoc. Prof. Petra Marešová
General Chairman of Hradec Economic Days
Faculty of Informatics and Management
University of Hradec Kralove

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Leveraging Business Model Innovation for Digital Transformation in Iraq

Sarkawt A. AHMED AL-DAWOODI¹, Ghaith AL-ABDALLAH² and Veronika VEČEŘOVÁ³

¹ Tomas Bata University in Zlín, Zlín, Czech Republic; al_dawoodi@utb.cz

² University of Kurdistan Hewler and the Catholic University in Erbil, Erbil; Iraq; Ghaith.abdallah@outlook.com

³ Mendel University in Brno, Brno, Czech Republic; veronika.vecerova@mendelu.cz

* Corresponding author: al_dawoodi@utb.cz

Abstract: This study aims to explore the drivers, challenges, and outcomes of digital transformation (DT) in traditional Iraqi businesses by assessing their transition strategies and major performance implications. Conducted through qualitative research, it examines seven enterprises across diverse industries in Iraq via semi-structured interviews with their senior executives. The motivation for this study lies in the critical role DT plays in fostering economic recovery and growth in developing countries like Iraq, which is navigating the dual challenges of post-conflict reconstruction and rapid technological advancements. The findings identify key drivers of DT, including the need for competitiveness, operational efficiency, and enhanced customer engagement. However, the transformation is hindered by challenges such as limited access to advanced technology, cultural resistance, skills shortages, and inadequate regulatory frameworks. Despite these obstacles, DT has led to significant improvements in operational efficiency, customer experience, and market competitiveness. The study emphasizes the importance of business model innovation (BMI) in overcoming barriers to digital adoption and advancing organizational resilience. The research evaluates the influence of DT on operational efficiency, customer engagement, and market competitiveness within Iraq's evolving economic environment. Key factors such as digital readiness, infrastructure investment, and workforce upskilling are essential for successful digital adoption.

Keywords: e-commerce; traditional business; advanced technology; data security; cultural resistance; sustainability

JEL Classification: M21; O10; O40

1. Introduction

DT has emerged as a pivotal catalyst for business expansion and competitiveness worldwide, particularly in developing economies such as Iraq. Despite Iraq is in the process of recovering from long periods of conflict and instability, traditional businesses (TBs) have technological, infrastructural, and regulatory challenges, making digitalization a source of both opportunity and obstacles. The COVID-19 pandemic expedited the global transition to digital business models (Awad et al., 2020); yet Iraqi businesses still face challenges like

outdated infrastructure, insufficient digital competencies, and cultural resistance to transformation (Shahoodh et al., 2020; Hussein et al., 2020).

The current literature on DT primarily focusses on developed economies, large enterprises, or certain sectors such banking or IT services. Nevertheless, there exists a considerable deficiency of focus regarding how TBs in Iraq, a developing country with unique cultural, economic, and technological conditions, navigating this process, what motivates their adoption of digital initiatives, and how does this transformation affect their financial success, operational efficiency, and consumer engagement? Comprehending these factors is crucial for formulating policies and strategies that facilitate digital adoption in developing countries, this study develops upon the recommendations of Salih et al. (2024), who underscore the necessity for cross-sectoral evaluations of DT in Iraq, extending beyond the banking sector to investigate SMEs across several industries. Shehadeh et al. (2023) argue for the widening of DT research into developing countries to comprehend the various challenges and opportunities that organizations encounter in these environments. Tian et al. (2023) reinforce this by advocating for research on the impact of DT strategies on operational improvements in developing countries, where digital ecosystems are still emerging. Despite the growing global interest in DT, there is an extensive absence of studies particularly investigating this phenomenon in Iraq.

This study aims to analyze the drivers, challenges, and outputs of DT in traditional Iraqi businesses. This qualitative analysis examines the impact of digitalization on business operations, market positioning, and customer interactions inside SMEs across several sectors. The research utilizes semi-structured interviews with top executives from seven businesses, providing insights on the determinants of digital adoption and the barriers that hinder successful transformation.

Three core questions guide this investigation: 1) What are the primary motives and drivers behind SMEs DT initiatives?; 2) What specific challenges and opportunities arose at the different stages of DT process?; 3) What is the impact of the DT on financial performance, operational efficiency, and customer experience? By addressing these questions, the results enhance the overarching discussion on digitization in developing economies and offer guidance for businesses and policymakers to navigate through this dynamic environment.

2. Theoretical Background

The business model serves as the fundamental framework for an organization's operations and strategic decisions (Bouncken, 2021). The framework explores the process by which the organization generates, distributes, and acquires value (Beulque et al., 2023; Salih et al., 2024). The business model, frequently referred to as an activity system, comprises a collection of interconnected activities that embrace not only the firm itself but also its partners, suppliers, and customers (Abdulkader et al., 2020). BMI involves the strategically planned process of modifying or redesigning the core components of a business model in order to provide new value for consumers, stakeholders, and the organization as a whole (Mao et al., 2023; Coffay & Bocken, 2023; Funke et al., 2023; van Eechoud & Ganzaroli, 2023). It entails reimagining how a company develops, distributes, and acquires value using new

technology, market opportunities, or customer behavior shifts. BMI impacts the value proposition, customer interface, core strategy, strategic resources, and value networks of the firm's model (Bashir et al., 2020). Innovation in the business model is a crucial instrument for gaining a competitive advantage and achieving long-term success in the market (Aboumoghli et al., 2012; Coffay & Bocken, 2023). An increasing number of businesses must innovate their business models to align with the era of DT (Bashir et al., 2020). The driving forces behind this are not only competition, but also the transition from product-focused to service-focused corporate strategies, the growing customer expectations for customized experiences, and the rise of disruptive technology in traditional industries (Spieth et al., 2014).

2.1. Traditional Business Model

The traditional business model (TBM) primarily centers around the production and trade of tangible goods, with minimal attention given to customer experience or value-added services (Bashir et al., 2020). In broad concept TBMs primarily priorities economic performance, often neglecting customer satisfaction and sustainability over time (Evans et al., 2017; Bouncken et al., 2021). They frequently consider environmental and social effect as external factors rather than incorporating them into their core business strategy (Viswanadham, 2018). The TBM may lack the flexibility required to adjust to rapidly evolving market conditions or customer demands, and may encounter difficulties in competing with digitally native enterprises that are founded on novel business models and technology-oriented innovation (Ramdani et al., 2019). Furthermore, modern business models are distinguished by a transition towards a platform-centric approach, wherein the organization serves as a mediator linking purchasers and vendors or facilitating transactions across various entities (Bashir et al., 2020). Bouncken et al. (2021) Suggests transitioning to a more agile, inventive, and customer-focused firm structure that can adapt to evolving consumer and technological environment. The term "traditional business model" usually refers to firms that are less adaptable, less digital, less likely to expand, and less focused on progressive transformation than their digital counterparts, Today's dynamic world requires accurate weather forecasts (Zahoor et al., 2023). These business models may encounter challenges in adapting to the COVID-19 epidemic, as they heavily depend on in-person interactions and transactions, which have been significantly limited owing to social distancing efforts (Kronblad & Envall Pregmark, 2021).

2.2. Business Model Innovation

BMI is the act of creating and executing new business models that utilize digital technology and capabilities to generate value for consumers and gain a competitive edge in the digital age (Schallmo et al., 2017). BMI entails reevaluating and restructuring different aspects of a business model's value proposition, creation, delivery, and capture, in order to effectively address the changing requirements and preferences of customers in a digitalized marketplace (Zahoor et al., 2023; Teoh et al., 2023).

BMI In today's digital landscape, organizations must prioritize innovation in order to maintain relevance and competitiveness (Rof et al., 2020). It enables businesses to connect

with customers in new ways, expand into new markets and distribution channels, optimize operations, and access into additional sources of revenue (Teoh et al., 2023). Furthermore, It enables businesses to employ data and analytics to get insights into customer behavior, enhance decision-making, and customize customer experiences (Vaska et al., 2021; Trischler & Li-Ying, 2023). Such models require a mindset shift, an embrace of novel technologies, and the development of digital competences within the firm (Teoh et al., 2023). Businesses globally, including as Iraq, must undergo DT in order to adapt and succeed in the continuously changing digital environment (Trischler & Li-Ying, 2023). Digital technology enable businesses to customize products and services and extend their local and worldwide customer base. They also enable firms to connect with a wider audience domestically and globally. BMI is crucial to stay competitive in a tech-driven environment and capitalize on new growth and innovation opportunities (Vaska et al., 2021). Digital technology allow companies to customize products and services to better match customer requirements. This helps match offerings to client preferences (Teoh et al., 2023). Financial services, hospitality, automotive services, and healthcare are using disruptive technologies to address sustainability and implement a sharing economy approach (Vaska et al., 2021). BMI entails monitoring business landscape shifts (sensing) and using digital technologies and capabilities to capitalize on them (seizing). This may necessitate changing or creating new business models. Sensing and seizing must be utilized for digital business model creation (Parida et al., 2019). Sensing recognizes potential modifications and possibilities, whereas seizing is taking action to exploit them, such as adopting new technologies, establishing partnerships, and reorganizing business procedures. A company's sensing and seizing ability can considerably impact their BMI (Zahoor et al., 2023; Böttcher et al., 2022).

Remane et al. (2017) provide a new way to find, create, share, and evaluate digital business ideas. VISOR analyzes digital business models on Value, Interface, Service Platform, Organizing Model, and Revenue. The value proposition is why customers buy. Interface links clients to service system. Service Platform powers product and service delivery. The Organizing Model contains value-creating company structure and procedures. The Revenue Model concludes with how ecosystem players share revenue and costs (Viswanadham, 2018; Remane et al., 2017). BMI boosts revenue and market share. Its complexity and difficulty in imitating make it valuable. To improve performance and grow in technology, businesses should prioritize BMI and carefully choose the best digital technology for implementing it (Teoh et al., 2023). Implementing BMI Organizations must actively identify industry trends and innovations in technology to drive innovation. They must also foster experimentation and learning (Rachinger et al., 2019; Al-Abdallah & Ogunbowale, 2023).

2.3. Digital Transformation

DT involves systematically integrating digital technology and capabilities into every aspect of an organization to transform its operations and improve customer value (Verhoef et al., 2021). Digitalization and business models require innovation. Digital business models related to digitalization and innovation are in a dual relationship. Technology and organizational innovations are needed and encouraged by the digital business model

(Bouncken et al., 2021). Digital technologies enable product and service integration across functional, organizational, and geographical boundaries. This integration enables businesses improve and expand their product and service offerings to create new values (Vaska et al., 2021). Consequently, these technologies promote the transformation of various industries. Their disruptive power forces businesses to reconsider their business strategies and adapt to digital reality (Trischler & Li-Ying, 2023). Enterprises, customers, partners, and other stakeholders must collaborate on digital platforms to enable DT (Bouncken et al., 2021). DT encompasses modifications in business culture, processes, and attitude as well as technical advancement (Warner & Wäger, 2019). Furthermore, digital technologies provide three intrinsic properties that create possibilities in connected domains: digital artifact, digital infrastructure, and digital platform (Vaska et al., 2021). DT modifies business models by adding digital components, overhauling previous value creation and capture methods (Kronblad & Envall Pregmark, 2021). DT changes a company's business model by integrating digital technologies. This integration intends to transform processes, boost customer value, and adapt to the digital age. DT fundamentally alters how the organization runs and delivers value (Kronblad & Envall Pregmark, 2021). In retail sector, this process involves integrating physical stores with online sales platforms, using digital payment systems, and using data analytics to customize consumer experiences and improve inventory management (Do Vale et al., 2022). Retailers must partner with specialized digital service providers to complete this transformation. Companies in the retail and digital service ecosystems collaborate to build a meta-ecosystem that benefits customers. Retailers handle retail, while digital agencies manage digital services in this meta-ecosystem. Digital solutions improve physical interactions, not replace them (Palmié et al., 2022a). DT integrates digital technologies and organizational improvements to boost innovation, efficiency, and customer satisfaction (He et al., 2023). Since digital technologies are becoming integrated into all corporate operations, digital strategy and business strategy will become interconnected (Chen et al., 2021). The DT is crucial for TBMs that are seeing disruptions caused by technological improvements and evolving the customer behaviors (Schallmo et al., 2017). For instance, traditional brick-and-mortar businesses may struggle to compete with internet retailers that offer convenience and customized experiences (Verhoef et al., 2021). While TDMs differ fundamentally from traditional ones, they can coexist and complement each other to effectively cater to the varied demands and preferences of customers (Schallmo et al., 2017). The process of DT encompasses more than just the adoption of new technologies; it also entails substantial modifications to the overall organizational structure and value delivery system (Verhoef et al., 2021), and necessitates collaboration and knowledge sharing among many functional divisions inside a business, such as marketing, IT, operations, and customer service, as well as external entities (Schallmo et al., 2017; Bataineh et al., 2016). Incumbent organizations sometimes struggle to innovate their business model due to the coexistence of the current model and the new model together with the value chain elements (Bouncken et al., 2021). BMI plays a vital role in facilitating DT by allowing businesses to develop novel value propositions, rethink consumer relationships, and seize new sources of revenue (Do Vale et al., 2022). Businesses that modify their business models can thrive in competitive markets

and effectively manage digital disruption (Warner & Wäger, 2019; Bouncken et al., 2021). This encompasses exploring of concepts such as subscription-based services, online marketplaces, and data-driven personalized solutions (De Souza et al., 2020). Furthermore, utilizing digital platforms and technology can improve productivity and customer satisfaction via digital inventory management, operational automation, and data analytics to derive insights and facilitate informed business decisions (Boojihawon & Ngoasong, 2018). Firms require a mindset that is entrepreneurial and a willingness to accept and manage risks in order to effectively navigate the process of DT (Palmié et al., 2022a). Drieschner et al. (2019); Türk (2023) argue that simply incorporating digital technology into existing business models is insufficient, and claims that firms must reconsider and redesign their entire process of generating value in order to effectively exploit the advantages of DT. Another argument is that the incorporation of digital technology into TBMs provides a possible challenge in adjusting to the rapidly evolving digital environment. The traditional organizational culture may conflict with the agility and adaptability necessary for DT, resulting in opposition and difficulties in implementation (Al-Bourini et al., 2013; Verhoef et al., 2021). Lack of technological competency and expertise in emerging technologies might also prevent a successful DT (Bouncken et al., 2021). Insufficient digital skills and expertise within the organization may prevent the achievement of successful DT (Bouncken et al., 2021). Therefore, it is imperative for businesses to allocate resources towards the training and education of their workforce in digital technologies and the change of business models (Drieschner et al., 2019; Al-Abdallah et al. 2023). Recognizing the complexity and risks of transitioning TBMs to DT, which requires significant investment in resources, training, and technology infrastructure, is crucial (Bouncken et al., 2021). DT is an essential procedure for TBMs that are encountering disruptions caused by technological breakthroughs and evolving the customer behaviors (Bouncken et al., 2021). Nevertheless, firms that completely embrace DT and adapt their business models can survive, thrive, and gain a competitive edge (Drieschner et al., 2019).

2.4. Digital Transformation in Iraq

Traditional Iraqi businesses may require the innovation of their business models to tackle the challenges of DT. In general, DT and DBMs can assist Iraqi TBs in overcoming challenges, expanding, and maintaining competitiveness in a rapidly evolving business landscape. Traditional Iraqi businesses must prioritize specific strategies and factors to effectively manage DT. This encompasses comprehending the impacts and advantages of DT, allocating resources for technology and infrastructure, prioritizing cybersecurity and data protection, promoting an appropriate legislative framework and incentives, and investigating novel business models. DT modifies the operations of organizations and value provision by incorporating digital technology into business and society (De Souza et al., 2020; Teoh et al., 2023). DT incorporates digital technology into every facet of business and society, altering business operations and value provision. The DT in Iraq has the potential to enhance economic growth, improve government service delivery, and elevate the quality of life for citizens (Salih et al., 2024). Iraq must execute DT to enhance governmental efficiency and

transparency, mitigate corruption, and advance healthcare, education, and public transportation services. DT might accelerate Iraq's assimilation into the global digital economy, drawing foreign investment and generating employment opportunities (Chen et al., 2021; Salih et al., 2024). Iraq can address infrastructural and security challenges to enhance digital connectivity and innovation through the adoption of DT. The governmental and private sectors in Iraq must invest in digital infrastructure, literacy, innovation, and entrepreneurship. Examine the labor ramifications of Iraq's digital transition. The transition to digital technology and intelligent systems may alter the work market, requiring reskilling and upskilling to address potential unemployment (Warner & Wäger, 2019; Salih et al., 2024). Effective DT requires strategic planning, substantial investment, and a comprehensive awareness of the numerous issues involved. As Iraq undergoes DT, businesses must acknowledge that their operations and culture will evolve. Digital technologies such as the Internet of Things, Artificial Intelligence, and Big Data necessitate technical and technological proficiency. This alteration necessitates a novel organizational business paradigm and culture that aligns with the demands of the digital age (Paul et al., 2020; ALmasoodi et al., 2023).

2.5. Challenges of Digital Transformation in Iraq

Traditional Iraqi businesses must comprehend the challenges and risks associated with DT prior to initiating the process. Challenges encompass, Traditional Iraqi businesses may lack the necessary digital skills and knowledge to comprehend and utilize emerging technologies such as the Internet of Things and artificial intelligence. They may have difficulties in incorporating digital technologies into their operations and business processes. Traditional Iraqi businesses may encounter opposition from employees and stakeholders who are either unfamiliar with digital technologies or concerned about job security. This resistance could hinder the digital transition and its efficacy. TBs undertaking DT may encounter challenges in Iraq due to inadequate internet and technological infrastructure. Traditional Iraqi enterprises must remain alert regarding potential hazards of digital transition, such as cyberattacks and data breaches. These risks erode customer trust and entail financial costs. Compliance with privacy regulations, data retention, and usage restrictions can complicate digital operations. Adopting and preserving new technology can be expensive, particularly for smaller financial institutions (ALmasoodi et al., 2023; Salih et al., 2024). To mitigate these challenges and risks, TBs in Iraq can take several steps. First, they can invest in building digital competence and expertise within their organization by providing training and educational programs for employees (Warner & Wäger, 2019). Second, they can work towards creating a culture of innovation and openness to change within the organization, addressing any concerns or fears related to DT (Reim et al., 2020). Third, TBs in Iraq can collaborate with technology providers and government organizations to improve access to technology and infrastructure. Additionally, they can prioritize cybersecurity and data privacy measures to protect their digital assets and maintain customer trust (Schneider, 2015). Furthermore, policymakers need to ensure that there is a supportive regulatory framework and incentives in place to encourage TBs in Iraq to embrace DT

(Kronblad & Envall Pregmark, 2021). As a result, this research will investigate the primary motives and drivers behind SMEs DT initiatives, the specific challenges and opportunities SMEs encountered at the different stages of DT process, and the impact of such transformation on the SME financial performance, operational efficiency, and customer experience.

3. Methodology

This study focuses on DT in Iraqi TBs. This study aims to comprehend how TBs in Iraq are undergoing DT and their impact on their performance. The reasoning for this study is deductive, as it involved doing a comprehensive analysis of existing literature in information systems, management, and business disciplines to identify crucial variables and challenges related to DT in TBs in Iraq (Sekaran & Bougie, 2016). Descriptive analytical methodology is most suitable, this methodology will help describe without any manipulation and analyze, the key drivers, challenges, and outcomes of DT among business owners and upper management individuals (Kothari, 2004). The research approach employed is qualitative, the data collecting technique employed is a semi-structured interview, wherein interviews were conducted with representatives from traditional firms in Iraq to obtain primary data regarding their experiences, challenges, and strategies pertaining to DT, this technique provides elasticity while preserving the structure of inquiry, allowing researchers to examine complex topics such as DT (Silverman, 2021). A method of qualitative research was used to thoroughly investigate the complicated nature of DT, facilitating the acquisition of comprehensive, nuanced data that quantitative methods may overlook. Comprehensive interviews afforded the opportunity to examine individuals' distinct viewpoints and experiences. This technique is limited by potential biases in self-reported data and difficulties in generalizing findings due to the small, non-random sample size.

3.1. Population and Targeted Population

A purposive sampling technique was employed to identify businesses that transitioned from traditional to digital models. This methodology was used to assure the inclusion of only those businesses possessing direct expertise in DT, allowing an in-depth review of their experiences, challenges, and responses (Ahmad & Wilkins, 2024).

Two prominent digital financial service providers, Fast Pay (Electronic Wallet) and FIB (Digital Bank), were contacted to acquire a list of registered enterprises involved in electronic payments. The number of companies and organizations registered in financial institutions to utilize internet banking services for online business in Fast Pay was 140, while First Iraqi Bank has 200 registrations, most of these businesses are startups. Businesses that transferred from traditional operations to digital models were recognized from the provided listings. This was derived from publicly accessible business data, direct corporate descriptions, and industry classifications. Thirty organizations that fulfilled the requirements for DT were identified as possible participants for the study. Executives from all 30 chosen businesses were contacted through direct calls to solicit participation in semi-structured interviews. Notwithstanding several follow-ups, only 7 executives volunteered for involvement in the

study. The study was undertaken from June 2024 to September 2024. The data gathering strategy mostly involved in-person meetings at the respondents' offices and video chats. Each interview spanned 45 to 90 minutes, facilitating comprehensive discussions.

Research conducted by the United Nations Development Program (UNDP) on Micro, Small, and Medium Enterprises (MSME) in Iraq highlights the challenges in determining the population for such studies in Iraq. One of the main reasons is that 83% of businesses are not registered in government related departments. The study also reveals that there is limited reliance on technology, such as the Internet, social media platforms, and E-commerce. However, 40% of the businesses surveyed reported using mobile phones in their daily operations (UNDP, 2023). The response rate was lower than expected, but the quality and relevance of the participants provided excellent insights into DT. The study admits this limitation and justifies the sample size based on the firm's detailed information. Secondary data sources, such as UN agency sector reports of the country, were used to strengthen the research. Finally, the study fulfills the purposive sampling minimum of five. (Tongco, 2007).

An overview of the selected businesses is presented in Table 1.

Table 1. Overview of businesses

Company	Industry	Number of Employees	Year of foundation	Position of Interviewee
Company A	Education	10	2020	CEO
Company B	Tourism	300	2010	Cofounder and Managing Director
Company C	Trading & Retail	20	2011	Founder and CEO
Company D	Trading & Retail	200	1997	Head of E-Commerce
Company E	Trading & Retail	200	2017	CTO
Company F	Real Estate	3,001 ¹	2002	IT Director
Company G	Trading & Retail	150	1943	CEO

¹ The number of employees at Company F is estimated and varies depending on the number of projects being implemented.

The respondents exhibited similarities, including engagement in the Iraqi market and having undergone diverse phases of DT. Although the group exhibited some heterogeneity in terms of industry and organizational size, their shared background established a robust foundation for recognizing similar themes and trends. Nonetheless, the findings may not comprehensively reflect all TBs in Iraq due to the limited sample size.

3.2. Research Instrument

Based on the sources provided and the focus on DT in Iraq, the following semi-structured interview questions for the qualitative research. These questions are designed to explore the processes, experiences, challenges, and impacts of DT on TBs:

1. What was the status of the company before the digital status phase in terms of customer satisfaction and performance?
2. What were the main drivers behind your decision to pursue DT? (Palmié et al., 2022b)
3. Can you describe the main steps your business took toward DT? (Ivančić, L. et al., 2019)

4. How did you assess the digital readiness of your organization before beginning the transformation process? (Ivančić, L. et al., 2019)
5. Can you elaborate on the challenges and risks your business faced during the DT process? And what strategy you employed to mitigate them? (Laudien & Pesch, 2019; Hussein et al., 2020)
6. How has DT impacted your customer relations and customer trust, particularly in terms of data security and privacy? (Hussein et al., 2020)
7. Can you provide examples of how DT has affected your business performance—either positively or negatively? (Li, L. 2022)

4. Results and Discussion

A systematic technique for qualitative data analysis was employed to guarantee the rigor and validity of the analysis. The gathered data were encoded and examined with NVivo software. The coding procedure engaged multiple discussion sessions to improve inter-coder reliability. Discrepancies in code were rectified by communication and agreement. NVivo enabled the systematic organization and analysis of coded data, facilitating the discovery of principal themes and sub-themes. The subsequent sections present these themes and sub-themes, accompanied by supporting samples from the data. This rigorous method guaranteed a thorough and nuanced comprehension of the complex factors affecting DT.

This research examined the motives, barriers, and outcomes of DT in traditional Iraqi businesses via semi-structured interviews with executives from seven firms. The study aimed to address three fundamental inquiries: 1) What are the primary motives and drivers behind SMEs DT initiatives? 2) What specific challenges and opportunities arose at the different stages of DT process? 3) What is the impact of DT on financial performance, operational efficiency, and customer experience?

4.1. Drivers of Digital Transformation

Findings reveal that competitiveness, cost minimization, and customer involvement were the main drivers for digital adoption. Competition emerged as a significant motivator, with businesses recognizing the need to adapt to survive in an increasingly digital marketplace, this aligns with global trends where businesses leverage digital tools to gain a competitive edge (Theme 1.1) (Spieth et al., 2014; Evans et al., 2017; Schallmo et al., 2017; Bouncken et al., 2021). The pursuit of organizational efficiency and cost savings further (Theme 1.2) underscores the pragmatic approach Iraqi businesses adopt towards DT, viewing it as a means to streamline operations and optimize resource allocation, the representative of company B said that “The management has decided to shift to digital operations in order to enhance operational control”, the literature highlights the role of DT in optimization of operations (Verhoef et al., 2021; Do Vale et al., 2022; Teoh et al., 2023). Furthermore, the emphasis on customer interaction and satisfaction (Theme 1.3) for personalized customer experiences and enhanced engagement emerged as a key motivator, A representative from Company A reported that: “Distinguish ourselves from the competition in order to expand

our customer base" aligning with the findings of (Spieth et al., 2014; Evans et al., 2017; Schallmo et al., 2017; Bouncken et al., 2021; Teoh et al., 2023; He et al., 2023).

4.2. Challenges and Risks During Transformation

Despite the recognized benefits, Iraqi businesses face significant challenges in their DT journeys. Limited access to advanced technology, particularly reliable internet connectivity, (Theme 2.1) poses a substantial barrier, emphasizing the need for infrastructural development to fully realize the potential of digitalization, "payment kiosk machines are used to resolve internet outages." Stated the Company F representative, this remains a critical concern in the studies of (Schneider, 2015; Bouncken et al., 2021; Warner & Wäger, 2019; ALmasoodi et al., 2023; Salih et al., 2024). Concerns regarding data privacy and security (Theme 2.2) highlight the importance of robust cybersecurity measures and regulatory frameworks to build trust in the digital ecosystem, The representative of Company A stated that "The copyright act is absent in Iraq". this finding was in line with the studies finding of (De Souza et al., 2020; Teoh et al., 2023; ALmasoodi et al., 2023; Salih et al., 2024). Cultural resistance to change (Theme 2.3), often stemming from a lack of awareness or fear of job displacement, underscores the need for change management strategies that address employee concerns and foster a culture of digital literacy, The representative of company G stated that "To minimize the risk associated with the change, I approached the younger staff with the assumption that they would be more receptive to it.". Warner & Wäger, (2019), Drieschner et al. (2019), Paul et al., (2020), Reim et al., (2020), Verhoef et al., (2021), Türk, (2023), ALmasoodi et al., (2023), and Salih et al., (2024) highlight the potential for cultural resistance to hinder DT adoption, emphasizing the need for organizational "mindset shifts" and embracing new technologies. Legacy systems (Theme 2.4) and a notable skills gap (Theme 2.5) further compound these challenges, emphasizing the need for investments in both technological upgrades and human capital development, Company D representative pointed out that "The logistics operation was centralized to a single site instead of picking up things from the branch closest to the customer's location. This has negatively impacted customer satisfaction in terms of both cost and delivery time". The last findings were in line with the finding in the studies (Warner & Wäger, 2019; Salih et al., 2024; Bouncken et al., 2021; Drieschner et al., 2019; Paul et al., 2020; ALmasoodi et al., 2023).

4.3 Impact of Digital Transformation on Business Performance

Despite these challenges, our findings demonstrate that businesses successfully navigating the digital landscape experience tangible benefits. Increased operational effectiveness through process automation and data-driven decision-making leads to improved efficiency and resource utilization (Theme 3.1), interviewee of company G stated that "The company primarily focuses on implementing online sales channels to enhance operational efficiency and effectiveness, based on the Six Sigma concept". Our finding is in line with the findings of studies (Teoh et al., 2023; He et al., 2023). Enhanced customer experiences and interactions through digital channels strengthen customer relationships and drive loyalty (Theme 3.2), as stated by representative of company E "Expanded the customer base, including a rise in the number of loyal consumers that

shop offline and online.”, Furthermore, DT fosters increased agility and innovation, enabling businesses to adapt quickly to market changes and explore new opportunities. These factors contribute to better sales generation and improved market competitiveness (Theme 3.3), positioning businesses for sustainable growth. The findings were confirmed by the findings of studies (Vaska et al., 2021; Do Vale et al., 2022; Trischler & Li-Ying, 2023; Teoh et al., 2023; He et al., 2023). Finally, Verhoef et al. (2021) argued that DT modifies the organizational structure and value delivery system, this is confirmed our finding of the integration of sustainability and corporate responsibility principles (Theme 3.4) through digital solutions highlights a growing awareness of the broader societal impact of business operations, “the application was developed from scratch necessitated to involve all departments in the company, focusing on the application interface to be friendly and maintain sustainability of development during the operation to cope to customer demand.” As reported by the representative of company F. Not all businesses had comparable advantages from the transformation, suggesting that the effectiveness of transformation is contingent upon industry type, investment in digital infrastructure, and staff adaptation.

5. Conclusions

The findings reveal that competitiveness, operational efficiency, and customer engagement are the primary drivers motivating DT efforts. Despite significant challenges, such as limited access to advanced technology, cultural resistance, digital skills shortages, and regulatory constraints, businesses that successfully navigate these barriers experience tangible benefits, including enhanced operational efficiency, improved customer experience, greater agility, and increased market competitiveness.

The study underscores the significance for business leaders of investing in worker upskills to bridge digital skill gaps, formulating strategic change management plans to mitigate cultural resistance, and enhancing cybersecurity while promoting clearer digital legislation. Policymakers could consider investing in internet infrastructure to facilitate digital growth, implementing legal reforms to rectify deficiencies in digital commerce legislation, and providing incentives for Businesses to embrace digital solutions. Collaboration among businesses, technology suppliers, and government organizations should be promoted to exchange resources, expertise, and best practices.

While the study offers valuable insights, its scope is limited by the sample size of seven businesses. Although the selected cases represent various industries and organizational sizes, they may not fully capture the breadth of experiences across Iraq. Consequently, the study's findings are indicative rather than representative, necessitating caution in generalizing the results. The theoretical contributions of this research lie in its exploration of DT in a developing country context, emphasizing the interplay of technological, cultural, and organizational factors. For managerial practice, the study highlights the importance of investing in infrastructure, upskilling the workforce, and fostering collaboration among stakeholders to create a supportive environment for DT. Managers are encouraged to prioritize strategic alignment between digital initiatives and organizational goals while addressing potential resistance to change through effective communication and training.

Future research should address the study's limitations by expanding the sample size and exploring DT in specific sectors such as healthcare, education, and logistics. Longitudinal studies could provide insights into the long-term effects of DT on organizational performance. Comparative analyses with other developing countries would offer a broader understanding of common challenges and innovative solutions. Additionally, examining employee perspectives on DT's impact on their roles, satisfaction, and productivity would yield a more comprehensive understanding of its organizational implications.

This study enriches the limited research on DT in Iraq by providing empirical insights into the motives, obstacles, and business implications associated with digitalization. Although findings indicate that DT can enhance efficiency and competitiveness, structural barriers and resistance to change persist as significant obstacles. Resolving these challenges through strategic investments, regulatory reforms, and workforce development will be crucial for securing a successful digital future for Iraqi businesses.

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Conflict of interest: none

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Ethics in Practice: The Experience of EU Fund Evaluators in the Czech Republic

Dita DROZDOVÁ, Miroslav JURÁSEK and Petr WAWROSZ*

Czech University of Life Sciences in Prague, Prague, Czech Republic; drozdovad@pef.czu.cz;
jurasekm@pef.czu.cz; wawrosz@pef.czu.cz

* Corresponding author: wawrosz@pef.czu.cz

Abstract: This study examines ethical challenges faced by evaluators of EU-funded projects in the Czech Republic, addressing gaps in existing research. Using a mixed-methods approach—including surveys, World Café discussions, and interviews—the study identifies key dilemmas such as balancing independence with stakeholder collaboration, pressures to distort findings, and/or data integrity issues. Findings highlight evaluators' strong commitment to impartiality, transparency, and accuracy, while systemic barriers like political pressures and incomplete data hinder ethical practices. Recommendations include enhancing ethical guidelines, providing targeted training, and establishing independent evaluation bodies to safeguard objectivity. The study offers practical insights for strengthening ethical standards and professionalizing evaluation practices in EU contexts.

Keywords: EU funds; evaluator; ethics; World Café

JEL Classification: H83

1. Introduction

Ethics in program evaluation is critical to ensuring accountability, transparency, and equity, particularly in contexts where evaluations inform significant societal and economic decisions (VÂRTEIU, 2016). It encompasses the assessment of research quality and impact while navigating complex ethical dilemmas, such as pressures to distort findings, selective reporting, or the suppression of unfavorable results. These dilemmas often arise in the multifaceted social, political, and organizational contexts in which evaluations occur (Kerssens-van Drongelen and Fisscher, 2003). Frameworks such as Kitchener's principles (Kitchener, 1984), the Program Evaluation Standards (Sanders, 1994), and the American Evaluation Association's (AEA) (<https://www.eval.org/>) Guiding Principles provide foundational guidance for addressing ethical challenges across all stages of evaluation.

Designing evaluations ethically requires methodological soundness, impartiality, and sensitivity to diverse worldviews (M. A. Morris, 2007; Schwandt, 2007). Evaluators must resist conflicts of interest and undue pressure to adopt biased approaches that compromise fairness. Ethical data collection involves informed consent, confidentiality, and harm avoidance, particularly in vulnerable or cross-cultural contexts (Groves Williams, 2016; Sanders, 1994). Waele et al. (2021) emphasize data protection as a frequent challenge in EU-funded projects. In data analysis and interpretation, evaluators face pressures to misrepresent

findings to satisfy stakeholder agendas. Barnett & Camfield (2016) note the prevalence of "clashes between right and right," where competing ethical principles require careful balancing. Transparent communication of results is equally vital, ensuring clarity, accuracy, and accessibility while safeguarding sensitive data (M. A. Morris, 2007). Simons (2006) highlights the importance of maintaining independence when reporting in politically sensitive contexts. Relationships with stakeholders must balance collaboration and independence to foster trust without compromising integrity (Samsonova-Taddei & Siddiqui, 2016). Active stakeholder involvement can enhance utilization of results, provided evaluators guard against undue influence (Okul & Nyonje, 2020). Ultimately, ethical evaluators ensure findings promote fairness, accountability, and societal benefit, aligning with broader goals like sustainable development (Brandão & Santos, 2023).

As we can see, many studies provide empirical evidence regarding ethical challenges faced by evaluators. Thus, key ethical challenges faced by evaluators include:

- Conflicts of interest (Gorman, 2018; Resnik, 2004),
- Necessity to meet tight deadlines or to accept incomplete or inaccurate data (Kerssens-van Drongelen and Fisscher, 2003),
- Reporting findings and misuse of results (M. Morris & Cohn, 1993; Simons, 2006),
- Stakeholder involvement (Brandon & Fukunaga, 2014), requests to tailor results or suppress negative findings to protect institutional interests, sometimes under threat of financial or professional repercussions (Calzoni, 2016),
- Data protection and confidentiality (Turcotte-Tremblay & Sween-Cadieux, 2018; Waele et al., 2021),
- Ethical dilemmas in complex or high-risk contexts (Ferretti et al., 2021; Wood, 2006).

Despite the increasing prominence of evaluation activities in the EU context, little is known about how evaluators in the Czech Republic experience and address ethical dilemmas in practice. This paper aims to bridge this research gap by examining the ethical challenges faced by EU fund evaluators and the principles guiding their decision-making processes. Specifically, we ask: What are the key ethical issues encountered by evaluators of EU-funded projects in the Czech Republic, and how do these influence their professional practices? By focusing on this underexplored context, the study seeks to provide practical insights that can enhance ethical evaluation standards and contribute to the professionalization of evaluators working with EU funds.

2. Methodology

2.1. Data Collection and Procedure

Three distinct methods were employed to collect data: a questionnaire survey, the participatory World Café method, and semi-structured in-depth interviews.

The questionnaire survey, designed to explore evaluation practices, ethics, professional development, stakeholder engagement, supplier relationships, evaluation impacts, and the professional identity of EU fund evaluators, targeted evaluators from managing authorities

identified through the Ministry of Regional Development – National Coordination Authority (NOK-MMR). Comprising 42 questions, primarily using five-point scales, the survey aimed to facilitate broad application, including presentations at the NOK-MMR conference. Administered online via Survey Monkey in October 2024, it achieved a response rate of 62.5% (30 of 48 evaluators). Although comprehensive, its length caused some participant disengagement. For this paper, only relevant sections of the survey were analyzed to align with the study's objectives.

A parallel survey, partially mirroring the first, was conducted among the managing authorities and private-sector evaluators to examine evaluation practices, professional development, client collaboration, evaluation impacts, and public procurement fairness. Respondents were identified through publicly available resources, including the Dynamic Purchasing System of the Ministry of Regional Development and the online Library of Evaluations. Selected evaluators involved in EU fund evaluations were invited to participate, with additional distribution using the snowball method. The survey, consisting of 40 questions in various formats (scales, multiple-choice, and open-ended) and demographic information questions, collected both quantitative and qualitative data, offering a nuanced perspective on evaluators' experiences. Only sections pertinent to this study were analyzed using descriptive statistics in Excel and SPSS v. 29.

The World Café method was implemented during a session of the Evaluation Working Group, coordinated by NOK-MMR, in September 2024. This participatory approach facilitated group discussions across four thematic areas: professional identity of evaluators, ethics and independence, stakeholder engagement and evaluation use, and innovations such as artificial intelligence. Participants, including managing authority representatives, rotated among thematic tables moderated by facilitators, who guided discussions with pre-defined questions. Key insights were documented and shared in a plenary session. This paper focuses exclusively on findings from the discussion on ethics, examining how evaluators of EU funds perceive ethical challenges in their work, the principles guiding their decision-making, and the impact of ethical considerations on their professional practices.

To further complement the survey findings, six semi-structured in-depth interviews were conducted online by the Ministry of Regional Development in October 2024. Three representatives from managing authorities and three external evaluators from supplier organizations participated in these one-hour interviews. Guided by detailed scripts, the interviews addressed evaluators' roles, challenges, and perspectives on professional identity and development, among other topics. Participants provided in-depth insights into challenges, potential solutions, emerging trends, and ethical considerations within the evaluation field. This paper reports exclusively on findings related to ethics in the work of evaluators, offering a focused analysis of ethical challenges, decision-making, and their implications within the evaluation community.

2.2. Respondents

The survey encompassed evaluators from both managing authorities and supplier organizations, offering valuable insights into their demographics, education, and

professional experience. Among managing authority evaluators (N=30), gender distribution was evenly balanced, with 50% men and 50% women. The majority (63%) fell within the 41–50 age group, while 29% were aged 31–40, and 8% were over 50, indicating a predominance of mid-career professionals. Educational qualifications were overwhelmingly high, with 96% holding Master's degrees and 4% having postgraduate qualifications; no participants reported having secondary or Bachelor's level education. Academically, respondents came from diverse fields, primarily Economics and Finance (22%), Social Sciences (22%), and Regional Studies (19%). Most participants had extensive experience, with more than six years in the field and an average of 17 evaluations conducted throughout their careers, reflecting significant professional involvement.

The sample of evaluation suppliers (N=12) similarly represented a highly experienced cohort. The gender distribution included 40% women and 60% men. Most respondents (60%) were aged 41–50, with smaller groups under 30 (20%) and over 50 (10%). Like their counterparts, they were highly educated, with 60% holding Master's degrees and 30% having postgraduate qualifications. Their academic disciplines were varied, with Regional Studies (22%) and Social Sciences (22%) being prominent, alongside other fields such as Economics, IT, and Education. Their professional experience surpassed six years on average, with participants reporting an average of 30.5 evaluations conducted during their careers. This highlights a multidisciplinary group of skilled professionals bringing significant expertise to evaluation work.

3. Results

3.1. Quantitative Analysis

The graph (Figure 1) quantifies the frequency of ethical dilemmas evaluators encounter in their work. Most responses fall in the "Never" or "Rarely" categories, accounting for approximately 75% of all responses. For example:

- Pressure to distort results: Over 80% of respondents indicated "Never" or "Rarely."
- Suppressing or omitting negative findings: Almost 80% reported these occur "Never" or "Rarely."
- Accepting incomplete or inaccurate data: Around 80% selected "Never" or "Rarely."
- Selective presentation of results: While still infrequent, 12% of respondents marked "Sometimes" or "Often."

The chart employs color coding to emphasize these trends. Green shades dominate the distribution, representing 70–90% of responses in the lowest frequency categories. In contrast, red shades, indicating "Sometimes" or more frequent encounters, account for 10–15% of responses for selective reporting and less than 5% for other dilemmas.

One respondent explicitly stated they had never faced such issues. Another, an evaluation commissioner, highlighted their commitment to ethical practices by fostering open discussions on findings rather than pressuring evaluators, further reinforcing transparency and collaboration in the evaluation process.

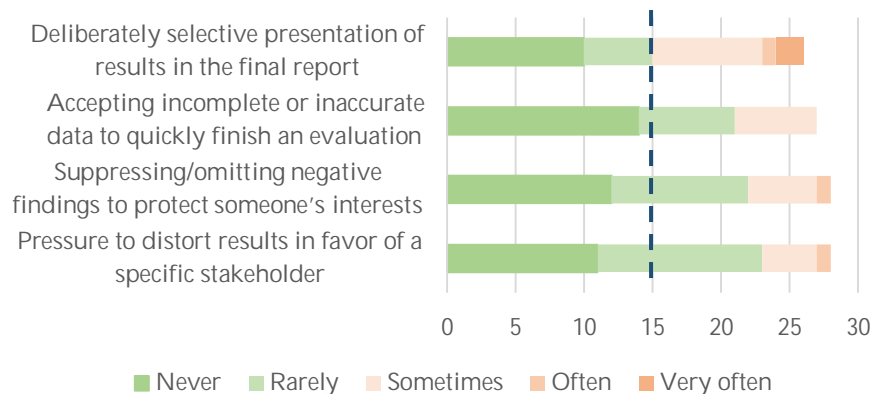


Figure 1. Ethical dilemmas faced by managing authorities' evaluators

Furthermore, the data shows that most respondents (managing authorities' evaluators) report no change in the frequency of encountering ethical dilemmas in evaluation work. For example, 80% noted stability in pressure to distort results, though 13% see it happening more often. Similarly, 69% reported no change in omitting negative findings, but 32% observed an increase. Inadequate data protection saw the highest rise, with 38% noting more frequent issues, while 63% reported stability. Selective result presentation also increased for 31%, though most (63%) saw no change.

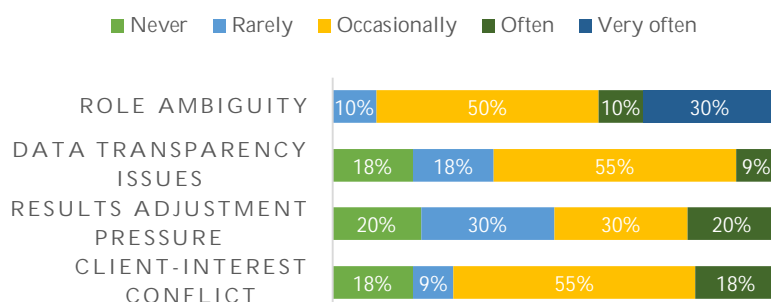


Figure 2. Frequency of ethical dilemmas in conducting evaluations for clients

A parallel survey among private sector evaluators working on public contracts commissioned by managing authorities revealed similar but distinct concerns. These evaluators addressed questions tailored to their context, focusing on challenges related to contractual pressures, adherence to procurement guidelines, and maintaining impartiality while managing diverse expectations from commissioning units. Key findings (see, Figure 2) include:

- Client-interest conflicts encountered occasionally by 55% of respondents, rarely by 9%, and never or often by 18%, with no reports of very frequent occurrences. These conflicts are relatively common but not consistently severe.
- Pressure to adjust results reported occasionally and rarely by 30% each, with 20% indicating they never or often faced such pressure. No respondents experienced this very often, suggesting a general commitment to integrity despite occasional challenges.

- Data transparency issues experienced occasionally by 55%, rarely or never by 18%, and often by 9%, with no reports of very frequent occurrences. These findings highlight variability in client openness, particularly in the public sector.
- Role ambiguity in decision-making encountered occasionally by 50% and very often by 30%, while 10% reported rare or frequent occurrences. No respondents indicated they never faced this issue, signaling a need for clearer role definitions in public-sector evaluation processes.

The respondents (managing authorities' evaluators) were also asked to evaluate the importance they place on specific principles during evaluations, using a scale from "Very important" to "Completely unimportant." The results reveal a strong consensus on the significance of transparency in communication, impartiality and objectivity, and responsibility for accuracy and precision. Transparency was highlighted as a critical value, with 70% respondents rating it as "Very important" and 20% marking it as "Rather important." Similarly, responsibility for accuracy and precision was deemed essential, receiving "Very important" ratings from 77% respondents and "Rather important" from 13%. Impartiality and objectivity emerged as the most universally prioritized principle, with 80% respondents marking it "Very important" and only 17% selecting "Rather important." Neutral or negative responses were minimal, and no participant rated any principle as "Completely unimportant." These findings demonstrate a shared professional commitment to ethical standards and high-quality evaluation practices, with impartiality and accuracy leading as top priorities and transparency closely following.

Similarly, private-sector evaluators were asked about changes in the importance of maintaining independence and objectivity when presenting evaluation results, even in challenging situations. While 55% reported stability in its importance, 27% noted an increase, suggesting growing recognition of these principles amid evolving professional demands, while 18% observed a decline, indicating that for some, emphasis on these values may have diminished in specific contexts. Overall, the data reflect a shared understanding among evaluators (from both groups) of the critical role these principles (transparency, objectivity, impartiality, responsibility for accuracy and precision) play in maintaining ethical and effective evaluation practices. Impartiality and accuracy emerged as the most universally prioritized values, with transparency following closely behind. This highlights a strong professional commitment to both ethical standards and the quality of evaluation outcomes.

The data show how evaluators handle findings that may be unfavorable for clients or organization. The most common approach (36%) is to present a balanced view of both positive and negative aspects, prioritizing fairness and transparency. Another 26% engage in discussions with clients or organizational leadership to address differences between expectations and findings, emphasizing collaboration. This approach suggests that dialogue is seen as a key tool for managing sensitive outcomes. 20% of respondents present results exactly as found, reflecting a strong commitment to objectivity, while 14% of them adapt presentations to make findings more acceptable, showing sensitivity to their audience. Only 5% suggest reworking the evaluation, preferring to address challenges within the original process.

Regarding adjustments to align results with client expectations, 30% of respondents report never witnessing such practices, reflecting a commitment to transparency. However, 70% acknowledge these adjustments occur, though infrequently—43% "Rarely," 23% "Occasionally," and only 3% "Often." While not widespread, these adjustments raise ethical concerns in some contexts.

3.2. Results of Qualitative Approach

This presents ethical challenges in EU fund evaluations, based on insights (using World Café participative approach) from managing authority evaluators participating in a regularly organized working group for evaluations coordinated by the Ministry of Regional Development. The discussions revealed critical ethical issues and highlighted areas for improvement in evaluation practices.

A key theme was the tension between independence and integration. While collaboration with clients helps ensure actionable results, excessive closeness risks compromising independence and objectivity. Participants emphasized the need for a balance that preserves both relevance and ethical integrity.

Concerns about external suppliers were prominent. Participants reported that some suppliers still adjust findings to align with client expectations, although such practices have declined. Supplier reputation also heavily influences the acceptance of findings, raising concerns about fairness and objectivity in the evaluation process.

Data integrity and presentation were highlighted as significant ethical challenges. Evaluators reported pressures to frame findings in ways that align with political or organizational agendas, underscoring the importance of rigorous ethical standards in reporting and communication.

Specific ethical concerns included collecting sensitive data, such as on minority groups, and adhering to GDPR regulations. Participants also noted systemic barriers, including political pressures and selective use or dismissal of inconvenient findings, which undermine transparency and accountability in evaluations.

To address these issues, participants proposed strengthening ethical training for evaluators and management, fostering transparent communication, and establishing independent evaluation bodies to reduce political pressures. Improving data collection and reporting standards was also highlighted as critical to maintaining the credibility of evaluations. While ethical practices and data quality in evaluations have improved, significant challenges remain. A continued focus on ethics, transparency, and professional development is essential to ensure evaluations support evidence-based decision-making effectively.

The analysis of semi-structured interviews with both EU fund managing authorities and public sector evaluators was focused on identifying ethical challenges and systemic barriers in the evaluation processes, as experienced by key stakeholders in the Czech Republic.

A recurring theme was the tension between maintaining independence and ensuring the utility of evaluations. Managing authorities highlighted political pressures to align evaluation findings with pre-existing policy priorities or political narratives. This often led to

selective presentation of findings or "desk drawer" evaluations, where inconvenient results were shelved instead of acted upon. On the supplier side, evaluators reported instances where clients explicitly or implicitly expected results to support specific outcomes, undermining objectivity. The lack of clear ethical guidelines for such situations exacerbated these challenges.

Both managing authorities and suppliers pointed to issues surrounding data collection and interpretation. Suppliers noted instances where the data provided by clients was incomplete, biased, or outdated, creating difficulties in producing accurate and credible evaluations. Moreover, GDPR compliance and the handling of sensitive information emerged as critical concerns, particularly in evaluations involving vulnerable populations. Concerns about methodological rigor were also raised. Some evaluators observed that cost pressures and tight timelines often led to compromises in data quality, which, in turn, affected the reliability of findings. There were calls for better training and resources to ensure methodological integrity.

The dynamics between evaluators and their clients revealed additional ethical concerns. Suppliers expressed frustration over vague or poorly defined terms of reference, which often resulted in misaligned expectations and frequent revisions of deliverables. Managing authorities acknowledged that their own lack of clarity at the outset sometimes contributed to these issues. Reputation bias also emerged as a concern. Some evaluators noted that well-established suppliers often had their findings accepted without scrutiny, while newer or smaller firms faced higher barriers to credibility, regardless of the quality of their work.

A disparity in the use of evaluation findings was observed. While some managing authorities reported integrating evaluations into strategic planning, others treated them as formalities, with limited follow-through on recommendations. This inconsistent application reduced the perceived value of evaluations and highlighted a lack of systemic accountability.

A lack of formalized ethical training for both evaluators and managing authorities was identified as a gap. While there were some ad hoc efforts to improve ethical standards, these were neither systematic nor widespread. Participants suggested that targeted training could help address issues like data integrity, political pressures, and stakeholder engagement.

4. Discussion

The ethical challenges in EU fund evaluations have emerged as a focal point in research among managing authority and public sector evaluators in the Czech Republic. Using insights from a qualitative World Café approach/semi-structured in-depth interviews and a quantitative survey, this study highlights critical ethical dilemmas such as independence vs. integration, supplier-client dynamics, data integrity, systemic barriers, and professional principles, aligning with broader evaluation literature.

One of the most significant ethical dilemmas identified in the study was the tension between maintaining evaluator independence and fostering collaboration to ensure actionable results. Chelimsky (2006) highlights that evaluators often walk a fine line between independence and responsiveness to stakeholders, with evaluators needing to avoid becoming overly embedded in organizational interests. While collaboration addresses client

needs, excessive closeness risks objectivity. Hartlapp & Falkner (2009) and Leese et al. (2019) similarly highlight political pressures undermining independence. Supplier-client dynamics remain a concern, with occasional tailoring of findings to meet client expectations and reputation bias influencing credibility. Stufflebeam (2001) warns of client pressures compromising impartiality (Dvorak, 2014).

Next, evaluators in our study reported instances where incomplete, biased, or outdated data from clients hindered their ability to produce reliable evaluations. Political and organizational pressures further exacerbated these issues, leading to selective reporting (“desk drawer evaluations”) and compromised methodological rigor due to tight budgets and timelines. The issue of data integrity and methodological rigor is widely acknowledged in evaluation research. Patton (2014) stresses methodological rigor for credible outcomes. The findings of another study (Salandra, 2018) reflect broader concerns about reporting (selectively) biases under external (institutional and contextual) pressures.

Managing sensitive data under GDPR remains challenging, particularly when working with vulnerable groups. Tikkinen-Piri et al. (2018) highlight the complexities of GDPR compliance and the need for clear protocols. The survey confirmed a strong commitment to ethical principles: 92% prioritized impartiality, 88% accuracy, and 84% transparency. These align with (Thomann & Sager, 2019), who emphasize ethical integrity as central to evaluation credibility.

Building an ethical evaluation culture is a multidimensional effort that requires institutional commitment and continuous education. EU initiatives, such as capacity-building programs and harmonized ethical standards, aim to create a shared understanding of ethical practices among evaluators. These programs align evaluation practices with broader goals of fairness, accountability, and transparency. Research suggests that such initiatives enhance evaluators’ ethical decision-making capabilities and improve the overall quality and credibility of evaluations. However, ongoing efforts are necessary to adapt ethical standards to evolving contexts and address emerging challenge (Dvorak, 2014).

- Develop and disseminate comprehensive ethical guidelines to address issues like data integrity, independence, and reporting transparency.
- Implement regular training programs for both suppliers and managing authorities, focusing on ethical practices and methodological rigor.
- Streamline processes for sharing reliable data while ensuring compliance with data protection regulations.
- Establish independent evaluation units to mitigate political pressures and ensure objective evaluations.
- Improve the clarity and consistency of terms of reference to align client and supplier expectations.

In conclusion, the ethical practices of EU fund evaluators are indispensable for ensuring accountability, transparency, and fairness in public spending. By adhering to ethical frameworks, addressing challenges such as public procurement, data integrity, and

stakeholder pressures, evaluators play a critical role in upholding equity and trust in evaluation processes.

However, this study remains exploratory, with limitations related to the small sample size, and the reliance on snowball sampling, particularly among private-sector evaluators, which may influence the generalizability of findings.

Future research should employ larger, more diverse samples and consider longitudinal approaches to examine how ethical challenges evolve over time. Additionally, studies could explore the impact of emerging technologies, such as artificial intelligence, on ethical decision-making in evaluations and assess the effectiveness of ethical training programs. Continued refinement of ethical frameworks, alongside sustained institutional support, will be essential to address these challenges and maintain public trust in EU funding mechanisms amidst increasingly complex evaluation environments.

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Conflict of interest: none

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Context of Hospital Management, Quality of Care Provided, and Economic Impacts of Nosocomial Diseases

Tomáš GROH

Prague University of Economics and Business, Jindřichův Hradec, Czech Republic; groh.tomas@gmail.com

Abstract: Healthcare and population health are critical for the future economic prosperity of nations. The primary scope of this research paper is to discover if and how much space for improvement exists between known practices and reality in the context of hospital management, quality of care provided and economic impacts of nosocomial diseases for healthcare providers, particularly hospitals. Through a literature review and in-depth interviews with representatives of hospitals, the primary foci were identified. A solid foundation in existing concepts and theories was formed to develop a framework and economic model which in combination with quantitative research provides the opportunity to assess and discover whether intervention in structural setup may foster quality improvements, particularly a decrease of nosocomial diseases, which can lead to positive economic impact for hospital care providers. There is an unexpected finding that significant discrepancy exists between the reality of structural setup and the potential structural setup in relation to nosocomial diseases. Based on the evaluation of quantitative questionnaires from 21 hospitals, the potential was identified for improving structural settings from the measured level of 56% to a potential score of 100%. The level of 100% corresponds to the level of settings based on existing knowledge, and the achieved level of 56% represents their current level of application, which also represents the potential for improving the quality of care. Alongside the quality improvement potential, the study documents a significant positive economic impact of CZK 18.5 billion for hospital healthcare providers in the Czech Republic which can be reached by launching and managing targeted infection prevention measures. It is desirable to verify through further research whether targeted management interventions in hospitals can utilize the identified space and improve outcomes resulting in decrease of nosocomial diseases and ensuring a positive economic impact for hospital care providers.

Keywords: healthcare; management; hospitals; outcomes; economic analysis

JEL Classification: H51; I25; P46

1. Introduction

The quality and availability of high-quality healthcare is one of the primary prerequisites for the future economic growth of individual countries. Yet each year, poor health reduces global GDP up to 15 percent (Remes et al., 2020). For this reason, measures supporting the improvement of the quality and availability of healthcare in the form of added value for the patient form the main strategic parameter in healthcare system and management. The path

of healthcare transformation towards added value for the patient will also be a source of competitive advantage on the part of providers, and added value for the patient will become a critical parameter of the system (Porter et al., 2006).

Hospitals, as leading healthcare providers, are large enterprises and their management fundamentally influences the quality and safety of the healthcare provided. Patient safety combines human behaviour with processes and relies on organizational leadership (Jarrett et al., 2017). The structure of healthcare delivery drives the costs and the quality of the system (Porter et al., 2006). Contrary to traditional approaches to health-systems reform which emphasize cost containment, the trend towards value-based healthcare shifts the focus to continuous improvement in patient outcomes. Systematically measuring, tracking, and improving health outcomes over time can have a transformative effect (Larsson et al., 2022). This transformation should not overlook evidence-based management to increase the probability of delivering the best possible outcome.

The healthcare management field faces significant barriers to converting research to practice, foremost being the lack of awareness and acceptance of academic research by managers. Adapting academic research to managerial needs, promoting organizational change, and creating accountability for adopting evidence-based change are necessary steps for health management research to meaningfully impact managerial practice (Gautam, 2008). To that end, "evidence-based management" (EBM) encourages managerial decisions to be based on the best available knowledge proven by scientific research. As conventional wisdom goes, what is measured gets done (Maddock et al., 2019), and the EBM is part of the wider movement toward evidence-based practice in medicine and public policy. It is obvious the EBM approaches supported by economic evidence like cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and economical evaluation models argue that it makes sense to disseminate innovations and implement interventions also from the economic perspective in real hospital settings.

The movement to implement changes and close the research practice gap continues to have a prominent role in public health. This study is part of the wider research within the writer's overall dissertation thesis aiming to find a new holistic approach to decrease HAIs in hospitals and further foster the culture of continuous quality improvement to accelerate the shift toward value-based healthcare and to further improve the position of quality and availability of healthcare in the Czech Republic in international comparison.

1.1. The Research Topic

This research aims to develop a framework which defines the content and develops a model to evaluate the economical perspective of an intervention in the context of hospital management, quality of care provided and impacts of nosocomial diseases. The research defines and evaluates space for potential intervention within the structural setup and demonstrates potential benefits of an intervention calculated from the hospital care providers perspective in the Czech Republic. The focus on hospital healthcare providers' efficacy and added value for patients through decrease of nosocomial diseases is within the primary scope of this research.

High-quality care is less costly when there are more accurate diagnoses, fewer treatment errors, lower complication rates, faster recovery, less invasive treatment, and minimized need for treatment (Porter et al., 2006). Complication rates as listed by Michael Porter are directly linked to infections as one of the leading outcome indicators reflecting the value for patients. This indicator can be precisely measured in the number of nosocomial diseases, or healthcare-associated infections (HAIs), to evaluate healthcare outcomes. Indicators such as length of stay and infections are still the most frequent measures considered in the literature (Zanotto et al., 2021). Healthcare-associated infections (HAIs) occur in Europe at a significant number of 3.8 million infections annually, which then lead to significant economy burdens and cause up to 80,000 deaths yearly (Suetens et al., 2018). In the Czech Republic, these data are not sufficiently documented, although the professional public emphasizes the seriousness of this issue.

The research combining the structural evaluation and economic analysis from the providers' perspective should support the motivation to close the research practice gap and launch managed intervention in the defined area. Nevertheless, it is obvious that this research paper cannot cover the overall topic and further research will be needed to verify the intervention whether it leads or not to decrease of HAIs in real hospital settings.

1.2. The Theoretical Framework

The structure of healthcare facilities is critical. It is the basis for the behaviours of employees of individual providers, which is further directly reflected in the quality of care provided. In some ways, this structure could be the primary determinant of the quality of care that the system can deliver as a whole (Donabedian, 2002). Unlike the process, the structure is more clearly and more easily documented and is, therefore, in most cases, better administrable by management. As mentioned earlier, the structure includes vast content that can be divided into several main categories. In particular, these include: 1) Material equipment, which relates to both investment and consumption costs, 2) Human resources, focusing on employees' capacity, competencies, their development and training and 3) Organizational characteristics, which relate to defining organizational goals, organizational design, and organizational structure, as well as reporting, performance evaluation, reporting and reimbursement methods, etc. Many other efficient practices can be suggested to improve the sustainability of healthcare organizations: improvements in management practices, leadership practices, manager selection, the engagement of clinicians in management, the promotion of organizational culture and management style, the promotion of virtual health communication, environmental supply chain management, rational resource consumption, and waste management (Mostepaniuk et al., 2023).

There is an enormous scope of potential structural components that might influence the process and outcome. Based on recommended World Health Organization (WHO) guidelines, in-depth interviews with hospital professionals and the writer's knowledge related to the topic, four main areas were defined and investigated in the structural area for this research to evaluate if potential improvements exist to narrow the gap between what

is done and what can be achieved. The Donabedian quality framework was adopted for this research and the adaptation is part of Table 1.

Table 1. Adaptation of Donabedian quality framework

Structure	Process	Outcome
Selected structural categories to prevent HAIs in hospitals S1: Quality program definition S2: Detection and monitoring S3: Training and education S4: Use of right equipment	Complications caused by HAIs (main infection types) P1: Pneumonia P2: Urinary tract P3: Surgical site P4: Bloodstream P5: Others	Outcome tracking through HAIs indicator

The healthcare costs are rising alarmingly. Evidence-based management (EBM) is vital to identify the cost-benefit relationship of infection control measures. EBM is a family of approaches to organizational decisions that make use of four sources of evidence: scientific findings (particularly cumulative bodies of research), organizational information (such as data and contextual factors), practitioner judgment (including experience-based knowledge), and stakeholder interests and concerns (such as effects on and perspectives of employees, clients, and constituents representing the broader environment). The evidence-based practice movement began as a response to the underutilization of scientific evidence in healthcare (Rousseau, 2020). It is clear that the EBM approaches supported by economic evidence like cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and economical evaluation models which are primarily grounded in welfare economics and health economics form the theoretical foundation. The specific economic model developed in this particular analysis to calculate the potential positive impact of reducing HAIs is described in detail in Study 2 of this research.

2. Methodology

The research was conducted using quantitative statistical methods and was divided into two parts. Study 1 evaluates the structural setup and demonstrates the potential improvements to reduce HAIs. Study 2 applies the developed model and demonstrates the economic benefit for hospital providers in light of successful HAIs prevention.

2.1. Study 1 – Hospital Structural Setup Evaluation

In Study 1 selected parameters of the structure's categories are evaluated and the study seeks to answer the first research question (RQ1).

RQ1: At what level is hospital structure fixed, and how much room for improvement exists, compared to the defined benchmark?

The structure has been measured based on the processing of a structured questionnaire, which takes place in hospitals. There are 160 hospitals in the Czech Republic, which provide acute inpatient care. In 2022, these hospitals provided healthcare for the entire population of the Czech Republic through 1.8 million hospitalizations. The research focuses on larger

hospitals (hospitals with at least 200 beds) with a broader spectrum of hospitalizations. The analysis was conducted through structured interviews with 122 stakeholders in 21 hospitals (13% of the total number of hospitals), representing 24% of the total acute hospital bed fund in the Czech Republic. The research panel includes private hospitals (4 hospitals) as well as public hospitals (17 hospitals) and following criteria formed the sample. Selected hospitals represent various specializations and ensure that the findings apply to a variety of large hospitals. There are clearly defined selection criteria (hospitals with more than 200 beds and management willing to participate) relevant to the research objectives. The practical and logistical reasons for selecting hospitals with willing management are based on data accessibility and cooperation for the success of the research. These criteria ensured that the sample was appropriate for achieving reliable and valid results at this stage of the writer's research.

The questionnaire combines WHO recommendations for infection prevention and experienced-based questions. The questionnaire contains questions rated on a Likert scale, dichotomous questions and questions rated on Guttman scale. Individual answers are assigned a specific number of points, ultimately compared with the maximum possible number of points achieved in each category. The maximum number of points achieved was expressed as a base for evaluation (100%). The number of points gained compared to the base is expressed as a percentage representing the level of structural adjustment and the potential for improvement.

2.2. Study 2 – Evaluation of Potential Economic Impacts of HAIs Decrease for Hospitals

The assessment of potential economic impact is secondary only to the motivation to increase quality of care for hospital management, driving the motivation and assessment of the need to start an intervention in healthcare. Study 2 offers the base for this evaluation answering the research question (RQ2).

RQ2: What are the potential economic benefits of interventions reducing HAIs, calculated on the national level of the Czech Republic?

Nominal group technique (NGT) was used with three healthcare industry experts to define the economic evaluation model. NGT uses structured small group discussion to achieve consensus among participants and has been used for priority setting in healthcare and research (Manera et al., 2019). Defined data were processed according to Table 3. The developed economic framework utilizes the opportunity costs principle and considers the positive economic value of the alternative use of existing resources represented by capacity and costs compared to resources bundled to treat patients with HAIs.

3. Results

The final results of individual studies are presented in this section and are further discussed in the next two sections of this paper.

3.1. Results of Study 1 - Hospital Structural Setup Evaluation

Data analysis shows that hospitals have significant potential for improvement in their structural settings in all four selected categories (quality program definition, detection and monitoring, training and education and use of right equipment.). The hospital panel shows the best results in quality program definition to be 67% out of potential 100%. Hospitals have the most significant space in the monitoring and identification category, where the result of 33% was achieved out of a maximum possible 100%. Overall results are shown in Table 2.

Table 2. Structure score evaluation

Hospital Panels (structure evaluation)	Panel Results (in %)
S1: Quality program definition	67
S2: Detection and monitoring	33
S3: Training and education	64
S4: Use of right equipment	58
Average score	56

Study 1 documents significant room for improvement in structural settings, which gives a high probability of achieving positive economic effects in eliminating preventable HAIs, which can account for 32% of the total number of infections (Haley et al., 1980).

3.2. Results of Study 2 – Evaluation of Potential Economic Impact of HAIs Decrease for Hospitals

The developed formulas were used to calculate the potential economic impact. The final result in Table 3 shows a potential increase of income, cost utilization through providing additional services and cost saving in value of CZK 5.8 billion annually and potential cost saving in value of CZK 18.5 billion annually at the national level. All data and their sources used for economic calculation are part of Table 3.

The results of this research, as well as any additional research, are subject to limitations. In Study 1, these limitations are associated with using the Likert scale, where central tendencies in the respondents' answers are involved. In the Guttman scale, agreement with a particular item may not always be fully related to agreement with the previous item. Limitations in the questionnaire survey are addressed by the sample size and the fact that the questionnaire was completed in a face-to-face interview between trained interviewers and individual respondents.

The economic model described in Study 2 has its limitations in simplification, which is necessary due to the complexity of the topic in order to make the analysis manageable. The accuracy of the predictions also depends on the accuracy of the available data. For this reason, the database is based on official data reported by hospitals and processed by the State Institute of Health Information and Statistics (UZIS, 2024) and data reported by European Centre for Disease Prevention and Control (ECDC, 2024). These data sets have been used to set the reimbursement mechanism in the Czech Republic, and to the author's knowledge, more accurate data cannot be obtained at this time. When data was used from other sources, data are compared with published studies within a similar scope of research and assessed by experts from the HARTMANN-RICO company.

Table 3. The potential economic benefits of interventions reducing HAIs

Number of Variable	Description of Model Variable Item	Annual Value 2022 and Units	Data Sources and Citations	Used Calculation Formulas
V1	Total number of hospitalizations	1,801,891 Hospitalizations	(UZIS, 2024)	
V2	Total number of treatment days	9,910,401 Days	Calculation	$V2 = V1 * V9$
V3	Total hospital revenues	256.4 bn CZK	(UZIS, 2024)	
V4	Total hospital costs	249.1 bn CZK	(UZIS, 2024)	
V5	Hospital revenues from insurance companies	218.4 bn CZK	(UZIS, 2024)	
V6	Total revenues per hospitalization	142,295 CZK	Calculation	$V6 = V3 : V1$
V7	Total costs per hospitalization	138,244 CZK	Calculation	$V7 = V4 : V1$
V8	Hospital revenues per hospitalization from insurance companies	121,206 CZK	Calculation	$V8 = V5 : V1$
V9	Average treatment time per hospitalized patient (length of hospital stay)	5.5 Days	(UZIS, 2024)	
V10	Annual number of nursing days	9,910,401 Days	Calculation	$V10 = V1 * V9$
V11	Incidence of HAIs from all hospitalizations	5.10 %	(ECDC, 2024)	
V12	Average number of patients with HAIs	91,896 Patients	Calculation	$V12 = V1 * V11$
V13	Average increase in length of treatment due to HAIs	8 Days	(ECDC, 2024)	
V14	Total increase in duration of treatment due to HAIs	735,168 Days	Calculation	$V14 = V12 * V13$
V15	Documented HAIs preventability rate	32 %	(Haley et al., 1980)	
V16	Total number of potential savings of nursing days	235,254 Days	Calculation	$V16 = V14 * V15$
V17	Potential number of additional hospitalizations (newly treated patients)	42,774 Patients	Calculation	$V17 = V16 : V9$
V18	Average cost per day of hospitalization	25,135 CZK	Calculation	$V18 = V7 : V9$
V19	Average part of fixed costs per hospitalization	69.30 %	(UZIS, 2024)	
V20	Average part of variable cost per hospitalization (medical supplies and drugs)	30.70 %	(UZIS, 2024)	
V21	Fixed costs per hospitalization	95,803 CZK	Calculation	$V21 = V7 * V19$
V22	Variable costs per hospitalization	42,441 CZK	Calculation	$V22 = V7 * V20$
V23	Related HAIs treatment costs per day (central medications are excluded)	2,514 CZK	Qualified estimation and calculation	$V23 = (V7 * 0,1) : V9$
RESEARCH RESULT 1	TOTAL COST SAVING POTENTIAL (max. potential of cost decrease by eliminating all HAIs)	18.5 bn CZK	Calculation	RESERCH RESULT 1 = $V14 * V18$
RESEARCH RESULT 2	ADDITIONAL REVENUE OPPORTUNITY (potential use of resources to treat new patients due to elimination of all preventable HAIs)	5.8 bn CZK	Calculation	RESERCH RESULT 2 = $(V17 * V8) + (V16 * V23)$

Finally, the use of the NTG consensus method was chosen in the design of this economic model to ensure the most significant possible degree of objectivity within Study 2. Despite these limitations, the proposed financial model remains a sufficiently valid tool for understanding and predicting the economic impact of interventions to reduce HAIs at the national level of Czech Republic.

4. Discussion

Healthcare is characterized by a high degree of complexity and transparency of outcomes is a precondition for the transformation towards higher added value. The research confirms the significant improvement potential in structural settings, especially in measuring and monitoring (37% out of possible 100%), which should become one of the key drivers for successful implementation of measures through transparency. At the same time, Study 2 provides the economic argument and framework for implementing these interventions in value of CZK 5.8 billion on income and cost side and CZK 18.5 billion on the cost side.

The economic model presented in this study calculates the impacts of HAIs at the national level of the Czech Republic, which incurs several limitations on the model. These limitations are related mainly to data quality and availability. As the model focuses on hospital costs, the long-term health consequences for patients are not quantified in the model. The model can also not capture interactions between patients, healthcare workers, and the hospital environment. Capturing these dynamics accurately in a model is challenging, and these dynamics must be described and considered in implementing preventive measures to reduce HAIs at the level of a specific hospital. Despite these limitations, the model remains essential for understanding the financial impacts of nosocomial infections and can guide infection control policies at the national level.

The model calculating overall economic impact at the national level should be further improved and turned into a cost-benefit analysis at the hospital level. The implementation of evaluation of the structural settings at the level of individual hospitals, combined with efforts in terms of personnel capacity and motivation for change management, can have a fundamental impact on HAI decrease, resulting in quality improvement and cost decrease at the same time. At the individual hospital level, the structural setup evaluation allows for identifying strategies and concrete action steps to reduce infection rates and improve patient outcomes.

Nevertheless, each change and innovation needs the proper motivation in order to be applied. Handling the quality of patient care and economy while at the same time ensuring professionals' engagement is a central leadership task. For top healthcare managers to lead the pursuit of increased sustainability in healthcare, there is a need to balance the quality of patient care, economy, and professional engagement (Bååthe et al., 2023). As the defined structure relates to existing knowledge, reaching the economic impact is a change management question.

Change resistance, insufficient data transparency, capacity constraints, high levels of bureaucracy and overall healthcare complexity are the main barriers to implementing and managing the improvement measures. To overcome these barriers in practice, the

commercial relationship between hospital providers and insurance companies considering improvements in the quality of care provided can be utilized. Quality measures and proven process improvements might be positively incentivized in the mutual contracts between payers and hospitals to support real change management in the practice.

According to the writer's findings within the overall dissertation research, the key to exploiting documented economic potential and improving care quality is the implementation of management intervention and change management in the style supported by a debriefing approach. Based on existing theories such as Kolb's Experiential Learning Theory (Kolb, 2015) and Kirkpatrick's Theory: Four Levels of Training Evaluation (Kirkpatrick, 1996), in addition to the writer's knowledge and qualitative research input, a new Hospital Management Debriefing framework as a management tool was developed (Figure 1) to foster healthcare quality and efficiency improvements and benefit as much as possible from the total potential economic impact.

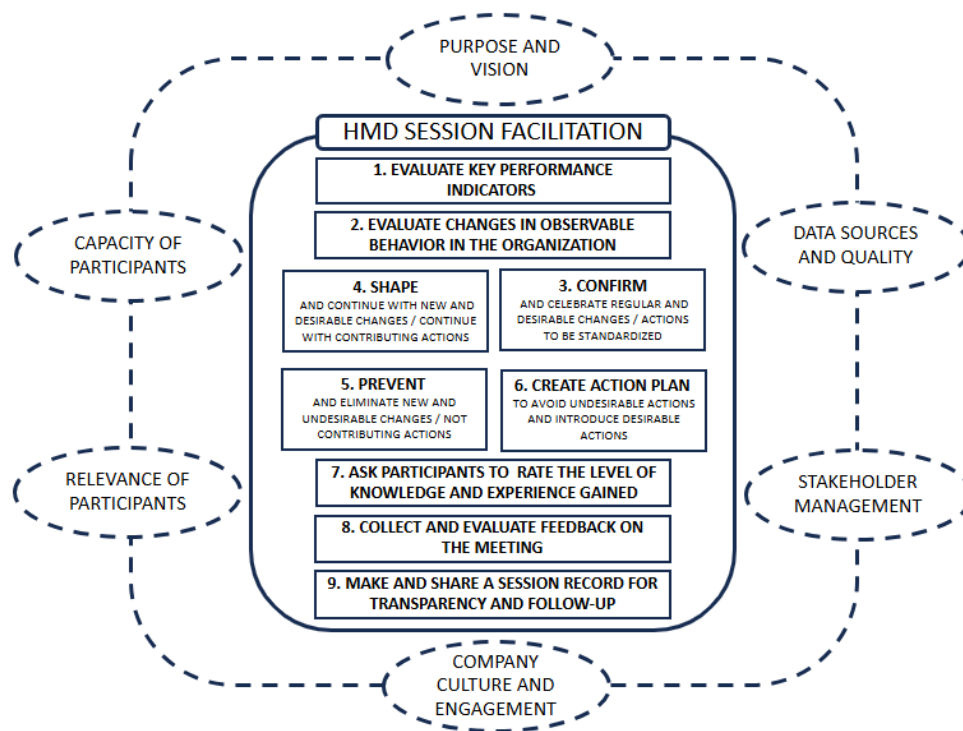


Figure 1. The Hospital Management Debriefing (HMD) framework

The situation in individual hospitals is unique, but according to the author, four areas of action are essential for achieving real change in practice. The first is the compilation of a specific action plan based on the evaluation of the questionnaire in the area of setting the structure at the level of individual hospitals. The second area of action is a fundamental improvement in monitoring and identifying HAls. This area shows the most significant room for improvement according to Study 1. At the same time, it is an area that plays a vital role in the third: the management of change using the newly defined debriefing framework as seen in Figure 1. The fourth area of action is the development of a more detailed economic model and conducting a cost-benefit analysis that can fundamentally support the implementation of measures in practice. This area should be the subject of further research within a practical experiment.

5. Conclusion

The research confirms the topic relevance and demonstrates a positive potential economic impact on hospitals and overall public health. There is a need to understand that the working environment with all stakeholders' behaviors and attitudes toward the implementation has a crucial impact on success (Rawshdeh et al., 2022). The success of healthcare innovation projects depends on effective management and alignment with the larger healthcare quality context (Tonjang et al., 2022). The pressure on the healthcare system, which is caused by the opening of scissors between demand and the finances necessary to meet it, will become a tremendous challenge in the near future. Further productivity increases and minimizing inefficiencies are the most feasible ways to improve healthcare quality further.

Continuing the research is vital to demonstrating how the gap in infection prevention can be narrowed and how the potential added value in quality for patients and positive economic impact for hospitals can be utilized. The practical experiment may demonstrate how the use of debriefing can turn potential benefits to reality and foster the management culture of continuous quality improvement with a positive impact on hospital providers and overall public health by transforming current practice towards higher added value.

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Critical Managerial Decision Making and Matrix Games

Jana HECKENBERGEROVÁ¹ and Pavel PRAŽÁK^{2*}

¹ University of Pardubice, Pardubice, Czech Republic; Jana.Heckenbergerova@upce.cz

² University of Hradec Králové, Hradec Králové, Czech Republic; Pavel.Prazak@uhk.cz

* Corresponding author: Pavel.Prazak@uhk.cz

Abstract: A manager's key task is to find the optimal solution, which can be difficult without advanced methods, data analysis or strategy evaluation. Game theory can help as a tool for decision making and achieving win-win outcomes in conflicts. Nash equilibrium applies to pure strategies, while matrix games without a saddle point require mixed strategies and linear programming. Given sufficient data, market competition can be modelled as a matrix game. This paper presents practical examples of the use of matrix games with linear programming in management. In particular, the paper deals with the following two decision problems: the conflict situation between two banks and the conflict situation between the company management and the trade union. Each case includes a formal description of the problem, the search for the optimal solution and the interpretation of the result from an economic point of view.

Keywords: decision making; matrix game; linear programming

JEL Classification: C61; C72

1. Introduction

1.1. Conflict Situations

Conflict occurs when individual goals clash. Effective communication and a positive group atmosphere help to prevent conflict. Sehnalova (2015) suggests five principles for resolution: realism, acceptance, prevention, mutual benefit and shared success. Conflicts occur when one's goal is constrained by the interests of others. Non-conflict situations have a single decision maker with clear outcomes. In conflict, each actor seeks an optimal strategy, taking into account the interests of others. In economics, this means maximizing profits or minimizing costs. The best solution is one that is acceptable to all parties (Šubrt, 2019; Hedvicakova & Prazak, 2018).

Game theory deals with multi-party conflicts, such as the allocation of advertising budgets or market expansion. It is used, for example, in the allocation of advertising expenditure or in the capture of new markets.

1.2. Decision-Making Process

The decision-making process consists of steps that lead to the optimal solution by identifying gaps between the current and ideal states. The decision maker sets evaluation criteria, either quantitative (e.g. profit) or qualitative (e.g. environmental impact), and compares options

accordingly. Decisions are made by individuals or groups within a defined problem domain. Options are evaluated on the basis of their consequences and criteria. Future scenarios can influence the results (Fotr & Svecova, 2010). Discrete models are divided into:

- Decision making under certainty - The decision-maker has complete information and knows with certainty what state of the world will occur. Analytic Hierarchy process (AHP) is designed for situations in which ideas, feelings, and emotions affecting the decision process are quantified to provide a numeric scale for prioritizing the alternatives. The Linear Programming (LP) models are examples of these decision-making methods.
- Decision making under uncertainty - The decision-maker assumes that there are n possible contingent states whose probability is unknown. The choice of the best option depends on various principles that reflect the decision maker's attitudes, as well as on the degree of optimism or pessimism of the decision maker.
- Decision making under risk - The decision-maker knows all possible future situations, the consequences of each option and the probabilities with which these situations may occur. Bayesian analysis is used to make the decision using a loss matrix (Fiala, 1999).

2. Methods – Matrix Games

Game theory explores scenarios where two rational opponents aim to outperform each other, both with contradicting goals. Common examples include competitive advertising campaigns and military strategy development. In such strategic conflicts, both players (opponents) have a set of possible strategies (finite or infinite). Each strategy combination results in a payoff for one player and in an equal loss of the other. This is known as a two-person zero-sum game, (Bonanno, 2018; Tadelis, 2013; Carmichel, 2005; Gibbons, 1992; Brickman, 1989). Therefore, we can represent the game from one player's perspective only in terms of his final payoff. Labeling the players as A and B, with m and n strategies respectively, the game is usually presented as the payoff matrix to player A as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \quad (1)$$

The representation indicates that if A uses strategy i and B uses strategy j , the payoff to A is a_{ij} , and the payoff to B is $-a_{ij}$. Because games involve a conflict of interest, the basis for the selection of optimal strategies guarantees that neither player is tempted to seek a different strategy because a worse payoff will ensue. The solution of the game is based on the principle of securing the *best of the worst* for each player. For the player A, this is represented by the minimum value of the entries in each row (*worst*) and by the maximum value of minimal column (*best*). So it corresponds to the maximin value of the given payoff matrix. Using same approach for the player B, *best of the worst* solution is based on the minimax value of the given payoff matrix.

In case that the payoff matrix A has a pure saddle-point

$$\text{maximin } A = \text{minimax } A = v \quad (2)$$

the optimal strategy for both players is a single pure strategy the value of the game equal to v . The pure strategy is also called Nash equilibrium and it is, in a way, the equivalent of the saddle point in the two-person zero-sum game.

When the game has no optimal *pure* strategy and the payoff matrix A has not saddle-point, the Nash equilibrium is replaced with a probability-weighted mixed strategy and the optimal value of the game will occur somewhere between the maximin and the minimax values of the game; (Taha, 2017)

$$\text{maximin } A \leq v \leq \text{minimax } A \quad (3)$$

2.1. Linear Programming Transformation

Let $\bar{X} = (x_1, x_2, \dots, x_m)$ be the vector of player A 's optimal probabilities that can be determined by solving the following maximin problem (Taha, 2017):

$$\begin{aligned} \max_{x_i} \left\{ \min \left(\sum_{i=1}^m a_{i1}x_i, \sum_{i=1}^m a_{i2}x_i, \dots, \sum_{i=1}^m a_{in}x_i \right) \right\} \\ x_1 + x_2 + \dots + x_m = 1 \\ x_i \geq 0, i = 1, \dots, m \end{aligned} \quad (4)$$

The equation (4) implies, that

$$\sum_{i=1}^m a_{ij}x_i \geq v, j = 1, \dots, n \quad (5)$$

Where

$$v = \min \left(\sum_{i=1}^m a_{i1}x_i, \sum_{i=1}^m a_{i2}x_i, \dots, \sum_{i=1}^m a_{in}x_i \right) \quad (6)$$

Player A 's problem thus can be written as maximize v subject to:

$$\begin{aligned} v - \sum_{i=1}^m a_{ij}x_i \leq 0, j = 1, \dots, n \\ \sum_{i=1}^m x_i = 1 \\ x_i \geq 0, i = 1, \dots, m \end{aligned} \quad (7)$$

Using a similar procedure, player B 's problem reduces to minimize v subject to:

$$\begin{aligned} v - \sum_{j=1}^n a_{ij}y_j \geq 0, i = 1, \dots, m \\ \sum_{j=1}^n y_j = 1 \\ y_j \geq 0, j = 1, \dots, n \end{aligned} \quad (8)$$

where $\bar{Y} = (y_1, y_2, \dots, y_n)$ is the vector of player B 's optimal probabilities solving the minimax problem.

The next step is to check that the payoff matrix does not contain negative elements. If it does, it must be converted to a strategically equivalent matrix with only positive elements. This can be done by adding the constant ω to all elements of the matrix. The value of the game is then equal to $v = v' + \omega$, where v' is the original value of the game. This procedure will ensure that resulting value v is nonnegative, $v > 0$. Last but not least, the new transformed variables have to be created as the fraction of probabilities and the game value v , $X' = (x'_1, \dots, x'_m) = \left(\frac{x_1}{v}, \dots, \frac{x_m}{v}\right)$ and $Y' = (y'_1, \dots, y'_n) = \left(\frac{y_1}{v}, \dots, \frac{y_n}{v}\right)$. (Volek, 2010)

Primal problem, solving the matrix game from player A 's point of view, then can be written as minimize $x'_1 + \dots + x'_m$ subject to:

$$\begin{aligned} a_{11}x'_1 + \dots + a_{m1}x'_m &\geq 1 \\ &\dots \\ a_{1n}x'_1 + \dots + a_{mn}x'_m &\geq 1 \\ x'_i &\geq 0, i = 1, \dots, m \end{aligned} \quad (9)$$

and dual problem, solving the matrix game from player B 's point of view, follows: maximize $y'_1 + \dots + y'_n$ subject to:

$$\begin{aligned} a_{11}y'_1 + \dots + a_{1n}y'_n &\leq 1 \\ &\dots \\ a_{m1}y'_1 + \dots + a_{mn}y'_n &\leq 1 \\ y'_j &\geq 0, j = 1, \dots, n \end{aligned} \quad (10)$$

The primal and dual solutions are closely related, in the sense that the optimal solution of either problem directly yields the optimal solution to the other. Thus, if the game has a solution in mixed strategy, the above symmetric dual problems have solutions:

$$\sum_{i=1}^m x'_i = \sum_{j=1}^n y'_j = \frac{1}{v} \quad (11)$$

3. Applications and Discussion

3.1. Conflict Situation Between Two Banking Institutions

Two banking companies, A and B , operate in the domestic market. Both offer many banking products, such as current accounts, term deposits, consumer loans, building savings, mortgage loans and many more. One of the products offered by both banks is a savings account.

The goal of each bank is to set an interest rate on the savings account that will retain existing clients and attract as many new clients as possible. For this example, the default

interest rate for Bank A was set at 5 % and for Bank B the default rate was set at 4 %. In the event of a reduction or increase in the interest rate, this would be by 1%. Both banks have three strategies to choose from when setting interest rates. These are the strategy of increasing the interest rate, decreasing the interest rate, or leaving the interest rate at the default rate.

In practice, the following situations may arise:

- Bank A decides to reduce its interest rates by 1%, and bank B adopts the same strategy. For player A, this means that despite the reduction, it will gain 5,000 new clients who will leave player B.
- If bank A reduces its interest rate to 4% and bank B increases its rate to 5%, it will result in 5,000 clients loose of bank A.
- If bank A reduces its interest rate to 4% and bank B does not change its interest rate, there will be no loss or gain of clients.
- If company A uses the second strategy, i.e. increasing the interest rate to 6% and institution B decreases its interest rate to 3%, bank A will gain 10,000 new clients.
- If company A increases its interest rate to 6 % and the other company also increases its interest rate to 5 %, company A will gain 3,000 new customers for its savings account.
- If Bank A increases the rate on its savings account to 6% and Bank B does not change its interest rate, the number of customers of Bank A will increase by 8,000.
- If Bank A chooses the strategy of keeping interest rates at the default level and Institution B lowers its interest rate to 3%, Bank A will gain 7,000 new clients.
- There may also be a situation where Bank A leaves its interest rate at 5% and Bank B increases its interest rate to 5%. Institution A will not gain new clients and Bank B will not lose any.
- The last possibility that may arise is to leave interest rates at their initial levels. What then happens is that Bank A gets 2,000 new clients who apply for a savings account with them (Jiskrová, 2023).

Optimal Solution of the Conflict Situation

There are two players in this conflict situation, namely Bank A and Bank B. Bank A has a choice of three strategies, namely to keep (K), increase (I) or decrease (D) its interest rate on the savings account. The opposing player, bank B, chooses from the same strategies. However, neither player knows in advance which strategy his opponent will choose.

The following payoff matrix is given from the point of view of banking company A. Elements of this matrix are the changes in the number of customers of the banking companies in thousands.

$$A = \begin{matrix} & \begin{matrix} D & I & K \end{matrix} \\ \begin{matrix} D \\ I \\ K \end{matrix} & \begin{bmatrix} 5 & -5 & 0 \\ 10 & 3 & 8 \\ 7 & 0 & 2 \end{bmatrix} \end{matrix} \quad \begin{matrix} -5 \\ 3 \\ 0 \end{matrix} \quad (12)$$

The first task is to find the saddle point of the payoff matrix. We add bottom line with max element of each column and we add last column with min element of each row. Nash

equilibrium has been found at position $a_{22} = 3$. It is the element that is the smallest in the added row and the largest in the added column.

Therefore, there is only one and most advantageous solution for Bank A to choose the strategy of increasing interest rates on its savings account. This will result in gain of at least 3,000 new customers of Bank A. Nevertheless, the same strategy must be assumed from Bank B as its market counterpart. Even after increasing the interest rates, Bank B offers a lower percentage on its savings compared to Bank A and it results in losing of 3,000 its customers that are attracted by Bank A offer.

3.2. Conflict Situation Between the Company Management and the Union of Employees

Company XY that manufactures automotive glass has the new CEO, a young and ambitious man was elected after the retirement of the previous one. He aims to introduce many changes and innovations in the company. One of them is to reduce costs by significant reduction in wages. In this company, there is the union of employees that should protect interests of the majority. At the first meeting between the new management and the union, the dissatisfaction of the employees with the working conditions and the wages paid was expressed. Workers were ready for rebellion, after the new director's announcement that wages would be reduced.

With the given company situation, the union wants to organize employee strike with the general goal to negotiate a wage increase and not a further fall. Company CEO can negotiate with the union on wages or not. Nevertheless, the management is aware about significant employee leave after a drastic wages' reduction.

After situation analyses, the employee union has come up with the following facts:

- Company CEO refuses to negotiate wage changes, nevertheless workers decide not to strike. This will result the decrease in total wages of 5 million CZK and a myriad of employees will resign their jobs because of insufficient and inadequate monetary rewards.
- The union decides to call a strike because there is no communication from the company management. As the result, CEO must concede and the in total wages will increase by 3 million CZK.
- Company managements is aware of union strength, and they will discuss wage levels together. Therefore, there is no need to strike and wages will increase by 4 million CZK in total. This outcome would be most beneficial for all employees and they would have no reason to leave their jobs.
- Negotiations between management and the union are not successful and then workers decide to strike. This will result the drop of total wages by 1 million CZK (Jiskrová, 2023).

Optimal solution of the conflict situation

Again, there are two players in this conflict situation, namely company CEO and employee union. CEO has a choice from couple strategies - negotiation (N) or no negotiation (NN), and the strategy couple for union is organize a strike (S) or decide not to strike (NS).

The following payoff matrix summarizes the total wage changes in million CZK.

$$A = \begin{matrix} & \begin{matrix} NN & N \\ NS & \begin{bmatrix} -5 & 4 \\ 3 & -1 \end{bmatrix} \\ S & \begin{bmatrix} 3 & 4 \end{bmatrix} \end{matrix} \end{matrix} \begin{matrix} -5 \\ -1 \end{matrix} \quad (13)$$

In this case, there is no saddle point and, therefore, no unique solution given by Nash equilibrium. Nevertheless, the whole problem can be solved as a mixed strategy game and be converted to a linear programming model. Following calculations respect company CEO point of view, best strategy for the employee union is evaluated afterwards.

First step requires the payoff matrix be positive, so let us create a new matrix A' by adding the value $\omega = 6$ to all elements of the matrix A .

$$A' = \begin{bmatrix} 1 & 10 \\ 9 & 5 \end{bmatrix} \quad (14)$$

Our goal is to find vector $\bar{Y} = (y_1, y_2)$, where $y_1 + y_2 = 1$ and y_1 resp. y_2 is the probability of choosing strategy (N) resp. (NN). The value of the game v lies in the interval $(5; 9)$ and following inequalities must be fulfilled:

$$\begin{aligned} y_1 + 10y_2 &\leq v \\ 9y_1 + 5y_2 &\leq v \end{aligned} \quad (15)$$

As the goal of CEO is to minimize the value of game v , the objective function given by $f(\bar{Y}) = \frac{1}{v}$ has to be maximized. To finalize the linear programming model, let us denote $y'_1 = \frac{y_1}{v}$ and $y'_2 = \frac{y_2}{v}$. Maximize $f(Y) = y'_1 + y'_2$ subject to:

$$\begin{aligned} y'_1 + 10y'_2 &\leq 1 \\ 9y'_1 + 5y'_2 &\leq 1 \\ y'_1, y'_2 &\geq 0 \end{aligned} \quad (16)$$

Initial Simplex tableau after the canonical form transforming is given as follows (Table 1):

Table 1. Initial Simplex tableau for model (16)

i	B_h	C_{Bh}	Y_h	-1	-1	0	0	$\frac{x_{ij}}{P_{ij}} > 0$
				p_1	p_2	p_3	p_4	
1	p_3	0	1	1	10	1	0	1
2	p_4	0	1	9	5	0	1	0.1111
m+1			0	1	1	0	0	

After two steps of Simplex method, we get the final Simplex tableau showing optimal solution of the mixed strategy game (see Table 2).

Table 2. Final Simplex tableau for model (16)

i	B_h	C_{Bh}	Y_h	-1	-1	0	0	$\frac{x_{ij}}{P_{ij}} > 0$
				p_1	p_2	p_3	p_4	
1	p_2	-1	0.0941	0	1	0.1059	-0.0118	
2	p_1	-1	0.0588	1	0	-0.0588	0.1176	
m+1			-0.1428	0	0	-0.0471	-0.1059	

Optimal solution $\bar{Y}' = (0.0588; 0.0941)$ with objective function value $f(\bar{Y}') = 0.1428 = \frac{1}{7}$ and the value of game $v = 7$. Now, let us return back to original game with payoff matrix A. Its value is influenced by $\omega = 6$ and therefore $v' = v - \omega = 7 - 6 = 1$. Optimal strategy for company CEO is given by probabilities:

$$\bar{Y}' = (0.0588 * 7; 0.0941 * 7) = (0.4; 0.6).$$

The optimal strategy from the perspective of the first player, i.e. from the perspective of the unions, can be solved as dual problem to model (16). Therefore, the solution elements can be found under complementary variables with opposite signs and the objective function has the same value. Therefore, the first player's strategy looks as follows:

$$\bar{X}' = (0.0471 * 7; 0.1059 * 7) = (0.3; 0.7).$$

The union is expected to strike with a probability of 0.7. If they do strike, there may be a possibility that the union will get extra money for its workers. Conversely, the probability that the union should not organize a strike is 0.3. The strategy that management should choose is as follows. The management should negotiate with the union to raise wages in the company with a probability of 0.6. If it decides to refuse to negotiate with the union on pay, it will do so with probability 0.4. According to the outcome of the value game, the union is expected to gain 1 million crowns in wages for the employees.

The best way to solve the problem is for management to talk about changes to wages. The union will probably strike to try to get at least a small increase in pay. Even a small raise shows that workers want to protect their interests and use the union to express their views.

4. Conclusion

This study investigates the utilisation of linear programming in managerial decision-making and matrix game theory, as exemplified by a series of practical case studies. Each case encompasses a formal mathematical problem description, the determination of the optimal solution, and an economic interpretation of the results. The study underscores the practical relevance of linear programming in matrix games and the optimisation of managerial decisions, highlighting its efficacy in resource allocation and decision-making processes. To illustrate this, the study introduces two case studies: the conflict situation between two banks and the conflict situation between the company management and the union of employees. The research underscores the significance of quantitative methods in business management.

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Conflict of interest: none

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Competencies of EU Fund Evaluators: Insights from the Czech Republic

Jan HOLICKÝ, Miroslav JURÁSEK and Petr WAWROSZ*

Czech University of Life Sciences in Prague, Prague, Czech Republic; holickyj@pef.czu.cz;
jurasekm@pef.czu.cz; wawrosz@pef.czu.cz

* Corresponding author: wawrosz@pef.czu.cz

Abstract: This study examines the professional identity, development, and challenges of EU fund evaluators in the Czech Republic, addressing a research gap in understanding their roles within managing authorities and the private sector. Data were collected through an online survey, the World Café participative method, and six semi-structured interviews. Descriptive statistics and comparative analysis explored trends and differences between the two groups. Findings reveal varied professional identities, with managing authority evaluators balancing evaluation with administrative tasks, while private-sector evaluators face pressures from procurement systems and limited recognition. Both groups report challenges such as administrative burdens, time constraints, and insufficient professional development. While conferences and self-study are common, tailored, hands-on training remains underutilized. This study highlights the need for targeted support to enhance evaluators' identity, skills, and recognition, contributing to more effective EU fund evaluations. It aims to strengthen evaluation practices, promoting transparency and accountability in public resource management.

Keywords: EU funds; evaluator; professional identity; professional competencies

JEL Classification: H83

1. Introduction

The effective evaluation of public funding is critical for ensuring transparency, accountability, and alignment with strategic objectives. Within the European Union (EU), evaluators of Structural and Investment Funds play a pivotal role in assessing project compliance, performance, and value for money. Given the scale and complexity of EU funding, the professional competencies of evaluators are essential for maintaining high standards in fund management.

Existing research highlights key competencies required of EU fund evaluators, including deep knowledge of EU regulations (Miserciu, 2019), technical skills in financial and operational auditing (Viorica & Alina, 2014), and analytical abilities for assessing complex data (Fleischhauer, 2005). Interpersonal skills such as proficiency in conveying findings clearly to stakeholders and ensuring transparent reporting are also vital (Kuligowski, 2023). Ethical conduct is another critical competency; evaluators are expected to act independently, avoiding conflicts of interest and maintaining integrity in assessments (Kuligowski, 2023).

Studies also emphasize the necessity of cross-disciplinary competencies. For instance, evaluators must integrate knowledge from diverse fields to manage and assess the multifaceted nature of EU-funded projects (Sonetti et al., 2020). Further, research underscores the role of governance quality and institutional capacity in ensuring efficient fund utilization (Blanco-Alcántara et al., 2022).

In the Czech Republic, EU funds are pivotal for regional and national development, supporting priorities such as research, education, and rural development. During the 2014–2020 programming period, 378 evaluations were conducted across 12 operational programs, with a total evaluation contract value of approximately 147.9 million CZK. The largest expenditure was under the Operational Programme Research, Development, and Education (OP VVV), which accounted for 99 evaluations and 11.1 million CZK (MMR, 2024). Strategic evaluations focused on regional development, inclusivity, and innovation.

External evaluations still dominate, but the total number of evaluations has decreased. The number of evaluations conducted during the second programming period (2014–2020) dropped significantly compared to the 2007–2013 period. The Ministry of Regional Development (MRD) was the most active in the first period but ceded its leading position in the second to the Ministry of Education, Youth, and Sports, which conducted 65 evaluations. A notable "riser" is the Ministry of Agriculture (MoA), which increased its evaluations from nearly zero to 37 (see Figure 1).

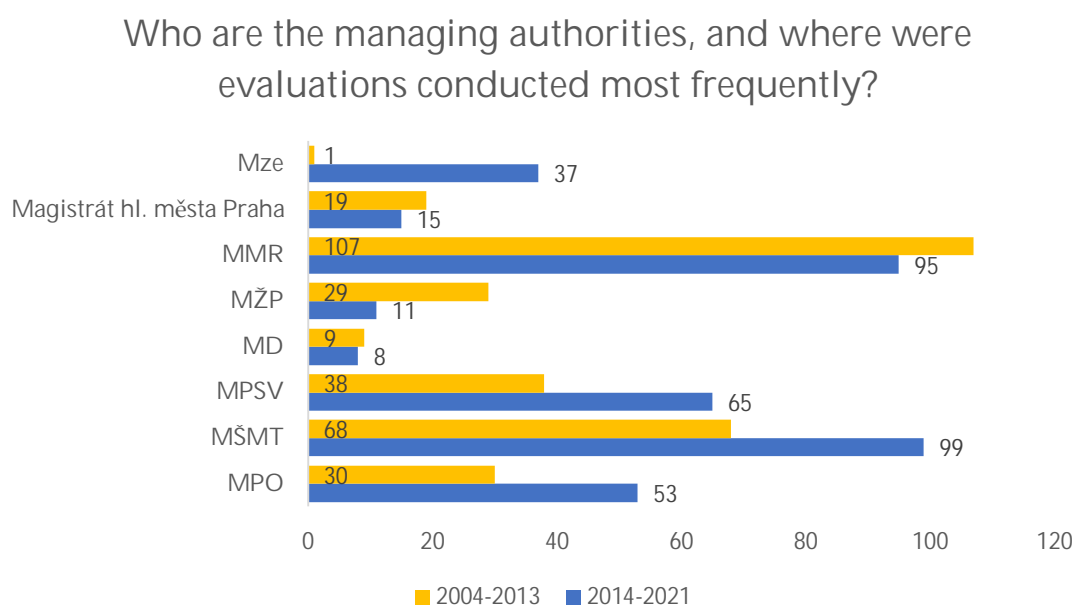


Figure 1. Number of evaluations conducted by managing authorities across two programming periods (2007–2013 and 2014–2020) (Ministry of Regional Development, 2025)

Note: MZe (Ministry of Agriculture), Magistrát hl. města Praha (Prague City Hall), MMR (Ministry of Regional Development), MŽP (Ministry of the Environment), MD (Ministry of Transport), MPSV (Ministry of Labour and Social Affairs), MŠMT (Ministry of Education, Youth, and Sports), MPO (Ministry of Industry and Trade)

External evaluations continue to dominate, with internal evaluations remaining rare. Moreover, their share of the total evaluations conducted during the 2014–2020 programming period decreased by 5% compared to the previous period (from 31% to 26%). Mixed evaluations are conducted only sporadically, with this evaluation design used in just a few cases.

Despite significant investment, research reveals inefficiencies in fund utilization, influenced by institutional weaknesses and management capacity. These challenges highlight the need for targeted training and professional development for evaluators (Mohl & Hagen, 2010).

This study explores the professional competencies, satisfaction, and development of EU fund evaluators in the Czech Republic. It investigates how frequently evaluators engage in professional development activities, the perceived value of methods such as conferences and self-study, and changes in practices over time. It also examines satisfaction with the profession, sources of motivation, and perceptions of respect within the evaluator community. Common challenges and their impact on motivation and growth are analyzed.

This research contributes to understanding the unique challenges and opportunities faced by EU fund evaluators in the Czech Republic. It offers valuable insights to enhance professional competencies, foster community engagement, and improve fund management effectiveness. Enhanced governance and targeted interventions are essential to maximize the impact of EU Structural Funds (Lewandowska et al., 2015).

2. Methodology

2.1. Data Collection and Procedure

Three methods were used for data collection: a questionnaire survey, the participatory World Café method, and semi-structured in-depth interviews.

The survey, targeting evaluators from managing authorities identified through the Ministry of Regional Development – National Coordination Authority (NOK-MMR), covered evaluation practices, ethics, professional development, stakeholder involvement, relationships with suppliers, impacts of evaluations, and the professional identity of EU fund evaluators. It consisted of 42 questions, mostly five-point scales, and aimed for broad use, including presentations at the NOK-MMR conference. Conducted online via Survey Monkey in October 2024, it achieved a 62.5% response rate (30 out of 48 evaluators). While comprehensive, its length led to some disengagement. For this paper, only selected relevant sections of the survey were used to align with the study's focus.

A parallel survey (to some extent identical to the previous one) targeting private-sector evaluators explored similar themes, including challenges in evaluation practices, professional development activities, client collaboration, evaluation impacts, and public procurement fairness. The main suppliers were identified through public open resources and the DNS system of the Ministry for Regional Development and online Library of Evaluations. (Ministerstvo pro místní rozvoj, 2025). Selected respondents involved in EU fund evaluations were contacted to complete the questionnaire, and a snowball method was employed, asking them to redistribute the online link to their team members. Using 40 questions in various formats (scales, multiple choice, and open-ended), the survey collected both quantitative and qualitative data, providing a nuanced understanding of evaluators' experiences. Only the sections relevant to this paper's objectives were analyzed, using descriptive statistics in Excel and SPSS, v. 29.

Then, the World Café method was implemented during a field session of the Evaluation Working Group coordinated by the Ministry of Regional Development's National Coordination Authority (NOK MMR) in September 2024. This participatory technique facilitated group discussions across four key themes relevant to evaluation practices: professional identity of evaluators, ethics and independence, stakeholder engagement and practical use of evaluations, and innovations including artificial intelligence.

Participants, including representatives from managing authorities, rotated between thematic tables moderated by facilitators, each focusing on pre-defined questions. Discussions emphasized sharing ideas, building on previous insights, and collectively exploring challenges and opportunities in evaluation. Facilitators documented key takeaways, which were later shared in a plenary session. The insights gathered during this event will inform future evaluation practices and development initiatives. This paper reports exclusively on the results from the group discussion on the professional identity of evaluators, exploring how evaluators perceive their roles, recognition, and the evolution of their expertise.

To supplement findings from the questionnaire survey, the Ministry of Regional Development conducted six one-hour online semi-structured in-depth interviews in October 2024. These interviews followed detailed scripts tailored for two groups: three representatives from managing authorities and three external evaluators from supplier organizations. The interviews explored evaluators' roles, challenges, and perspectives on key evaluation themes, including professional identity and development. The discussions covered topics such as current challenges in evaluation, potential solutions, future trends, and professional development practices. Participants could provide in-depth insights on different topics. For this paper, only findings related to professional identity and development of evaluators are reported, offering a focused analysis of these critical aspects within the evaluation community.

2.2. Respondents

The survey targeted evaluators from managing authorities and suppliers, providing insights into their demographics, education, and experience. Among managing authority evaluators (N=30), there was equal gender representation (50% men, 50% women). Most respondents (63%) were aged 41–50, with 29% aged 31–40, and 8% over 50, reflecting a predominance of mid-career professionals. Nearly all held advanced degrees (96% Master's, 4% postgraduate), with no respondents reporting secondary or Bachelor's education. Their academic backgrounds were diverse, primarily in Economics and Finance (22%), Social Sciences (22%), and Regional Studies (19%). Most had over six years of experience, averaging 17 evaluations per career, reflecting strong professional engagement.

The sample of evaluation suppliers (N=12) also showed a highly experienced group, with a gender split of 40% women and 60% men. The majority (60%) were aged 41–50, with smaller proportions under 30 (20%) or over 50 (10%). Most held advanced degrees (60% Master's, 30% postgraduate), with varied academic fields, including Regional Studies (22%), Social Sciences (22%), and other disciplines like Economics, IT, and Education. Their experience

exceeded six years, with an average of 30.5 evaluations per career. This highlights a skilled, multidisciplinary group contributing substantial expertise to evaluation activities.

3. Results

3.1. Quantitative Analysis

Managing authority evaluators are motivated by contributing to social change (59%), learning new things (52%), and contributing ideas (44%), while autonomy, policy impact, and variety of methods are less valued (22%). Personal insights highlight a need for greater collaboration and decision-making influence. Private-sector evaluators prioritize creativity (18%), policy impact, and intellectual challenges (15% each), while societal impact (9%) and collaboration (6%) are less significant. Notably, personal idea contribution is not seen as a motivator. Both groups value creativity and intellectual engagement but differ in priorities, with managing authorities focusing on societal impact and private-sector evaluators emphasizing policy influence. Enhanced collaboration and autonomy could improve satisfaction for both.

However, both groups of evaluators face challenges, with 78% of managing authority respondents reporting excessive workload and 71% citing frequent time constraints. In the private sector, 75% face resource limitations and time constraints often, and 72% report frequent administrative burdens. Ethical dilemmas are rare for managing authorities (67%) but moderate for private evaluators (25%). Systemic issues like low budgets and unfunded tasks add pressure for private-sector evaluators, highlighting a need for improved support and resources (see Figure 1).

Despite these work challenges, the evaluators from both groups reported high job satisfaction. Among managing authority evaluators, 63% are satisfied, 26% neutral, and 11% dissatisfied, with no reports of strong dissatisfaction. This indicates generally positive views, though room remains for improvement in engagement and satisfaction. Private-sector evaluators show even higher satisfaction, with 84% reporting they are satisfied (17% very satisfied, 67% rather satisfied), and no neutral responses. However, 16% express dissatisfaction (8% rather dissatisfied, 8% very dissatisfied), highlighting challenges such as workload or limited growth opportunities. While satisfaction is predominant in both groups, addressing the concerns of the dissatisfied minority could further enhance professional fulfillment.

Both managing authority and private-sector evaluators show mixed perceptions of the respect for the evaluator profession in the Czech Republic. Among managing authority evaluators, most respondents lean toward neutral or agreement, with many selecting "Agree" or "Strongly Agree," indicating a generally positive view of respect for the profession. However, a notable minority disagrees, reflecting concerns about insufficient recognition. Private-sector evaluators display a similar trend, with 58% expressing a positive perception (8% "Definitely agree" and 50% "Rather agree"). However, 33% hold negative views, including 25% who "Rather disagree" and 8% who "Completely disagree," while 8% remain neutral. While the majority in both groups perceive some respect for the profession, the

significant neutral and negative responses highlight a need to enhance the visibility and value of evaluators to improve recognition and respect across the professional landscape.

Both managing authority and private-sector evaluators show varying levels of connection to the evaluation community in the Czech Republic, with opportunities for improvement in fostering inclusivity. Among managing authority evaluators, 54% feel a positive sense of belonging, while 35% remain neutral, and 12% feel disconnected. Most respondents express moderate levels of connection, indicating room to strengthen engagement and inclusivity. Private-sector evaluators display a similar pattern, with 42% feeling positively connected, including 25% who "definitely" feel part of the community. However, the largest group (33%) expresses neutrality, and 25% feel somewhat disconnected. Notably, none report feeling completely excluded, signaling potential for increased outreach and integration. Both groups highlight a need for initiatives to enhance collaboration, communication, and opportunities for involvement to foster a stronger sense of belonging within the evaluation community in the Czech Republic.

Both managing authority and private-sector evaluators demonstrate mixed perceptions regarding the importance of professional recognition. Among managing authority evaluators, 45% consider recognition important, while 33% are neutral, and 22% find it unimportant. This suggests a significant portion values recognition, but ambivalence among many highlights an opportunity to strengthen its perceived relevance. Private-sector evaluators show a similar pattern, with 42% valuing recognition, including 17% rating it as "very important" and 25% as "rather important." However, 50% take a neutral stance, indicating recognition may not be a priority for many, possibly due to a focus on other professional aspects like impact or collaboration. Only 8% consider it unimportant, and none dismiss it entirely. Overall, while a portion of evaluators appreciates professional recognition, the neutrality among others suggests a diverse range of motivations. Efforts to emphasize the role of recognition in fostering motivation and community cohesion could benefit both groups while balancing other professional priorities.

Professional development participation differs between evaluators from managing authorities and those from private suppliers. Among managing authority evaluators, the majority (63%) participate 2–3 times per year, with 23% engaging more frequently (4 or more times annually), indicating a moderate commitment to continuous learning. However, 13% rarely or never participate, suggesting possible barriers. In contrast, private supplier evaluators show a wider range of engagement. Equal proportions (33%) participate either 2–3 times a year or 6 or more times annually, reflecting a significant segment with a high commitment to professional development. However, 17% never participate, and smaller groups (8% each) engage a maximum of once or 4–5 times annually, resulting in a weighted average participation rate of 3.25 times per year. While both groups demonstrate regular engagement in professional development, private suppliers show a slightly higher proportion of frequent participants but also a higher percentage of non-participants, indicating more polarized engagement levels compared to the more consistent pattern among managing authority evaluators.

Currently, both managing authority and private-sector evaluators prioritize interactive professional development methods, with over 80% valuing conferences, workshops, and training sessions (Figure 2). Peer exchange and self-study are also important, though views are more divided. Reading journals is moderately valued, while professional associations receive the least support. Both groups highlight the need for more advanced training and networking opportunities to enhance their growth and collaboration.

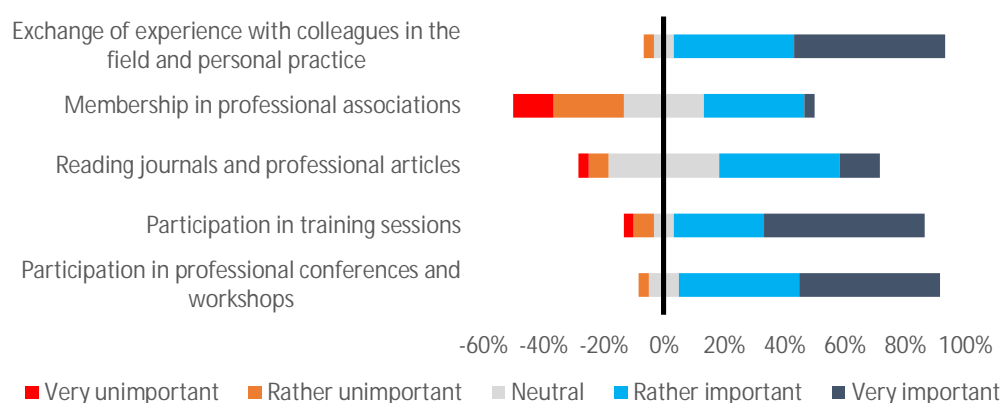


Figure 2. Key professional development approaches perceived as important by managing authorities evaluators

The respondents were also asked how they perceived the change in respect with their participation in different development activities over time. Both managing authority and private-sector evaluators report increases in participation in conferences, workshops, and self-study, with 52–75% seeing growth in these areas. However, membership in professional associations and training sessions shows mixed results, with some noting declines or no change. Reading professional literature remains stable for managing authorities but is increasingly utilized by private-sector evaluators. Open-ended responses reveal challenges in assessing professional development trends due to the decentralized and individualized nature of opportunities.

Evaluators report increasing engagement with advanced methods (63%), modern technologies (64%), and innovations (63%), reflecting growing interest in these areas. Ethical issues remain stable, with 91% seeing no change in engagement. Measuring program impacts and addressing data challenges show mixed trends, with 36–50% reporting increases, but some note no change or slight decreases. These findings highlight a general focus on technological and methodological advancements, with stable attention to ethics and variability in other topics.

Both managing authority and private-sector evaluators emphasize data, technology, and innovation in their professional development, reflecting their growing importance in evaluation processes. Among managing authorities, modern technologies and data challenges are the most frequently addressed topics, while ethics and stakeholder engagement are less prioritized, highlighting a gap in foundational training. Similarly, private-sector evaluators report moderate engagement with modern technologies (up to 25% responses “Often” or “Very often”), innovation, and impact measurement, though advanced

methods minimal focus, with up to 42% never engaging in these areas. Despite quality improvement being a well-addressed topic, both groups demonstrate the need for more balanced and comprehensive training that integrates technical skills with essential ethical and stakeholder strategies (see, Figure 3).

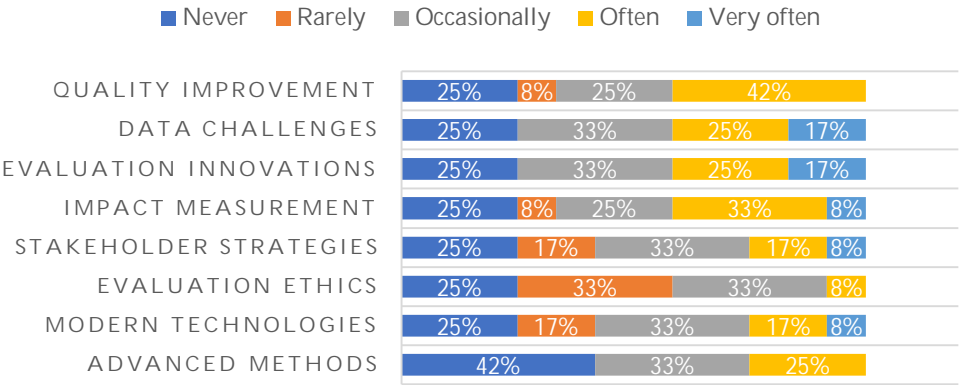


Figure 3. Frequency of training in key evaluation topics

3.2. Results of Qualitative Approach

The qualitative analysis of the World Café method provides insights into evaluators’ professional identity, recognition, expertise, and development needs. As for the professional identity, evaluators fall into three groups: dedicated evaluators focused solely on evaluation, coordinators managing evaluation-related tasks, and part-time evaluators for whom evaluation constitutes a small portion of their workload. This diversity reflects varying roles shaped by organizational priorities. While international recognition of evaluators has improved due to EU frameworks, national-level awareness remains limited. Evaluators often need to explain their role, particularly in non-EU-focused departments, highlighting the need for broader advocacy. Technological advancements, such as Power BI and big data, have enhanced evaluation capacity. However, unequal access to resources and training risks creating disparities in skills across units, affecting evaluation consistency.

Barriers to professional development include limited access to training, lengthy approvals, and insufficient practical application. Evaluators prefer tailored, hands-on training to address specific needs and enhance competencies effectively. These findings highlight the need for structured support to strengthen professional identity, recognition, and development, ensuring evaluators are equipped to address emerging challenges.

The qualitative analysis also draws on six semi-structured interviews with evaluators from managing authorities and private-sector organizations. The findings explored themes related to evaluators’ professional identity and their approaches to professional development, highlighting shared challenges and unique perspectives based on their organizational contexts.

As for the professional identity, evaluators in managing authorities described their roles as multifaceted, encompassing analytical tasks, evaluation coordination, and administrative responsibilities. Many emphasized that evaluations are often viewed as a bureaucratic necessity rather than a strategic tool for decision-making. This perception undermines the

recognition of evaluators as integral contributors to organizational learning and policy improvement. Participants noted the importance of organizational independence to foster a clearer professional identity, distinguishing evaluators from other administrative functions.

In the private sector, evaluators reported challenges in defining their professional identity, often shaped by competitive pressures and pricing-focused public procurement systems. Some described feelings of professional isolation, mitigated through participation in evaluation networks. Others highlighted the evolving nature of their roles, with increasing demands for impactful evaluations despite constraints such as rigid procurement rules and cost-cutting measures. Private-sector evaluators emphasized the importance of their work in bridging analytical rigor with actionable insights for stakeholders, despite limited recognition of their expertise.

Professional development in managing authorities is marked by uneven access to resources and time constraints. Participants highlighted barriers such as limited training opportunities, inadequate support for skill enhancement, and significant administrative burdens. While the evaluation culture has improved due to EU requirements, many evaluators cited inefficiencies in public sector systems, such as access to modern tools and data systems, as ongoing challenges. Internal training programs were noted as valuable but insufficient to address advanced methodological needs.

In contrast, private-sector evaluators often rely on self-directed professional development. Many participants emphasized the need for practical, hands-on training tailored to their specific roles, particularly in advanced data analytics and emerging technologies such as artificial intelligence. Collaborative development within teams was also highlighted as an effective way to maintain quality and innovation. However, limited institutional support and external training opportunities pose significant obstacles to continuous growth.

4. Discussion

The findings reveal a fragmented professional identity among evaluators, particularly in managing authorities where evaluation is seen as bureaucratic rather than strategic. This reflects the broader challenge of establishing evaluators as key contributors to policy and organizational learning, as noted by (Podems, 2014), who emphasized that professional identity is central to advancing the field.

The evolving nature of evaluator roles, from technical analysts to policy advisors, requires redefining their purpose within organizational structures. The international perspective offered by Buchanan and Kuji-Shikatani (2014) on the Canadian experience mirrors these findings, as Canadian evaluators also report struggles in defining their roles due to diverse pathways into the profession and varying levels of organizational support. Advocacy for evaluators as essential to evidence-based decision-making is crucial. This could involve campaigns to highlight the profession's strategic value, leveraging success stories where evaluations have driven significant social or organizational change.

Both groups' focus on advanced technologies and methods illustrates the increasing importance of equipping evaluators with cutting-edge skills. However, gaps in foundational training, particularly in ethics and stakeholder engagement, indicate the need for a more balanced approach. Clinton and Hattie (2021) argued that cognitive complexity must be embedded in evaluator training to address the gap between "knowing that" and "knowing how," enabling evaluators to navigate complex challenges.

The findings align with the Canadian Evaluation Society's emphasis on professionalization through comprehensive competency frameworks. Yet, disparities in training access, particularly in managing authorities, highlight systemic inequities that could hinder the adoption of these frameworks. These disparities underscore the importance of adaptable training models, such as competency-based learning pathways that cater to diverse evaluator needs and contexts.

The moderate sense of belonging reported by evaluators in both sectors underscores a need to foster stronger community ties. The literature highlights the role of professional associations and networks in creating inclusive environments for evaluators to exchange knowledge and build connections. King et al. (2001) emphasized that a strong professional community not only enhances individual growth but also strengthens the collective identity of the field. Workshops, peer exchanges, and participatory learning methods resonate with Stevahn et al. (2005), who argued that interactive professional development is essential for embedding reflective and interpersonal competencies. Creating spaces for evaluators to collaborate on cross-sectoral projects could further enhance their sense of belonging while fostering innovation.

The reported high workloads and administrative burdens among managing authority and private-sector evaluators reflect systemic issues that impede professional growth and satisfaction. This resonates with findings from Buchanan and Kuji-Shikatani (2023), who highlighted similar challenges in the Canadian context. Structural reforms are critical, including streamlining administrative processes, increasing budgets, and providing flexible work arrangements to mitigate burnout.

The literature also advocates for integrating professional development opportunities into routine work schedules, reducing the tension between learning and workload. For instance, Podems (2023) suggested embedding ongoing training into organizational practices to align capacity building with professional demands. Stevahn et al. (2005) emphasized that foundational skills, such as ethics and stakeholder management, should remain central to competency frameworks, ensuring evaluators are equipped to handle both technical and interpersonal dimensions of their work.

Both evaluator groups reported valuing conferences, workshops, and interactive training sessions. However, disparities in participation rates, particularly among private-sector evaluators, suggest barriers to access. This echoes the findings of Dewey et al. (2008), who highlighted gaps between competencies taught in academic programs and those sought by employers. Addressing these gaps requires aligning professional development opportunities with real-world demands, such as offering practical, context-specific training in advanced data analytics and emerging technologies.

The increasing focus on technology and innovation in evaluation reflects broader trends in the field. Clinton and Hattie (2021) highlighted the importance of evaluators understanding how to navigate and leverage vast amounts of data to make informed judgments. However, integrating these advancements into practice requires continuous investment in both tools and training.

Building on these insights, the following strategies could enhance the professionalization and satisfaction of evaluators:

- Strengthen initiatives to elevate the evaluator's role as a strategic contributor. Public campaigns and organizational advocacy should highlight how evaluations drive impact and policy decisions.
- Equitable Access to Training: Develop flexible, competency-based training models that address diverse needs. Online platforms and modular training programs could improve access for evaluators in resource-constrained environments.
- Expand regional and international collaboration opportunities, such as joint projects, mentorship programs, and knowledge-sharing platforms.
- Streamline administrative processes and increase funding for evaluation functions. These reforms could reduce workloads and create space for professional development.
- Integrate advanced technical skills with foundational training on ethics, stakeholder management, and interpersonal competencies, ensuring evaluators are holistically prepared.

Future research should explore the longitudinal impact of professional development on evaluator performance, particularly focusing on how advanced competencies (e.g., cognitive complexity and technological skills) influence evaluation outcomes. Comparative studies across diverse cultural organizational contexts would provide insights into how local dynamics shape evaluator roles and professional identities. Additionally, investigating the integration of emerging technologies, such as AI and big data, into evaluation practices could inform strategies to modernize the field.

This study has limitations, including a small sample size, with private-sector respondents recruited using a snowball method, making the sample non-representative. While the response rate among managing authorities was high, the accessible population is relatively small but well-defined. The cross-sectional design and reliance on self-reported data may introduce biases, limiting the generalizability of findings.

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Conflict of interest: none

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A Comprehensive Bibliometric Analysis of Electronic Invoicing: Examining Global Influence, Impact, and Adoption Trends

Irena HONKOVÁ¹, David ZEJDA^{2*} and Pavel BARTOŠ³

¹ University of Pardubice, Pardubice, Czech Republic; irena.honkova@upce.cz

² University of Hradec Králové, Hradec Králové, Czech Republic; david.zejda@uhk.cz

³ Evropská akademie vzdělávání SE, Prague, Czech Republic; pavel.bartos.pb@gmail.com

* Corresponding author: david.zejda@uhk.cz

Abstract: This study presents a comprehensive bibliometric analysis of the literature on electronic invoicing, spanning from 1994 to September 2024. A total of 413 papers were analyzed to understand the evolution and current state of research in this emerging field. Key insights were identified regarding the progression of research, influential authors, leading institutions, key fields, publishing indexes and the most cited authors. The study reviewed relevant literature using the Web of Science database. Several research gaps were identified, pointing to the need for further studies in electronic invoicing. These gaps suggest potential areas for future exploration that could significantly contribute to the development of the field. The study concludes that its findings will serve as a valuable resource for researchers, offering a structured overview of the existing literature and identifying critical areas for future research.

Keywords: e-invoice; electronic invoice; e-invoicing; electronic invoicing

JEL Classification: M0; M41; M48

1. Introduction

Electronic invoicing (e-invoicing) is gaining significant traction across academia, industry, and the global environment, driven by trends in business transformation, efficiency, and accuracy. It is projected, the e-invoicing market to grow by 28% between 2021 and 2025 (Marinagi et al., 2015). This innovation has become a global phenomenon, with increasing adoption by governments, organizations, and medium to large companies. Latin American countries, such as Brazil, Mexico, and Chile, have been pioneers and world leaders in the implementation of electronic invoicing systems (Bellon et al., 2022). While the overall adoption rate in North America is comparable to that of Europe, the growth rate in North America lags significantly behind both Europe and Latin America (Cedillo et al., 2018). In the Asia-Pacific region, e-invoicing is expanding on a country-by-country basis, whereas its adoption remains limited in Africa (Olaleye & Sanusi, 2017). The benefits of e-invoicing, such as its utility for taxation purposes and the enhancement of productivity and profitability for companies, have been major drivers behind its adoption across various jurisdictions (Edelmann & Sintonen, 2006).

The onset of the COVID-19 pandemic has impacted all business sectors and global economic activities, including the rollout and compliance with e-invoicing directives (Linh & Phuong, 2020). The pandemic's effects on e-invoicing are both positive and negative. On the positive side, the real-time transmission of electronic invoices for tax administration and other business activities supports the social distancing and isolation measures necessitated by COVID-19 (Hagsten & Falk, 2020). Additionally, e-invoicing is expected to play a role in the post-pandemic recovery process by enabling effective tax administration and improving decision-making processes in accounts payable and receivable (Kivijärvi et al., 2011). Conversely, the pandemic has disrupted the introduction, implementation schedules, and deadlines for e-invoicing including relevant legislation in various countries, presenting significant challenges to its global rollout (Tang et al., 2020; Bellon, et al., 2022).

Revisiting theoretical positioning and practical application should not be a daunting task for researchers, given its importance and relevance. There is a need for an overarching theoretical framework for e-invoicing, despite it being a rapidly growing field of study. As development occurs in waves, the diffusion of innovations theory (Bansah & Darko Agyei, 2022) may provide a useful framework for understanding the gradual spread of e-invoices. Fernández-Portillo et al. (2020) research integrates innovation and technology acceptance models. The technology acceptance model is based on the idea that factors such as perceived usefulness and ease of use are critical for the adoption of new technologies. If electronic invoicing systems are considered technological innovations, they are likely to undergo a series of stages before achieving widespread adoption (Shen et al., 2021). They analyze ICT developments, identifying three distinct stages: readiness, intensity, and impact. Intensity (or use) measures the percentage of enterprises adopting and the level of use, while readiness pertains to a firm's capacity to adopt ICT innovations. Impact refers to changes in behavior, economics, or productivity resulting from use.

Several studies have been conducted on electronic invoicing systems, including the benefits of e-invoicing for companies, attack detection technology for electronic invoicing systems (Matus et al., 2017), standards for generating and communicating electronic invoices, and the development of e-invoicing solutions. The study by Olaleye et al. (2023) presents a systematic literature review to map and clarify the current state of knowledge on electronic invoicing and the technological aspects related to notification systems. Despite the growing number of studies on this topic, reviews of articles on electronic invoicing remain very limited (Shim & Song, 2016). Thus, due to the lack of such literature reviews, this study conducts a bibliometric analysis to review articles related to electronic invoicing, aiming to identify the evolution of scientific research in this field. As its main goal, it provides a deeper understanding of the milestones achieved and intercontinental differences in electronic invoicing. It also demonstrates how to extend the study of electronic invoicing by pinpointing gaps in the literature, and considering variables such as institutions, and leading authors.

2. Methodology

The study reviewed relevant literature using the WoS database. Singh et al. (2020) note that WoS is a leading global citation database that covers high-quality research across different regions, countries, and knowledge domains. Singh et al. (2021) classified WoS as the most important multidisciplinary bibliographic database, and Zhu and Liu (2020) highlighted that this database is among the most widely used for bibliometric analyses. The literature suggests that WoS is more selective in its journal inclusion. The combination of its content quality and unique categorizing and search features made it suitable for the study. The chosen 1994 to 9/2024 timeframe provides sufficient volumes of scientific data for a quantitative bibliometric data analysis, including uncovering emerging trends in article, author, and journal performance.

Data collection and systematic selection according to PRISMA guidelines (Page et al., 2021), as shown in Figure 1 created in PRISMA Flow Diagram tool (Haddaway et al., 2022), was carried out in September 2024.

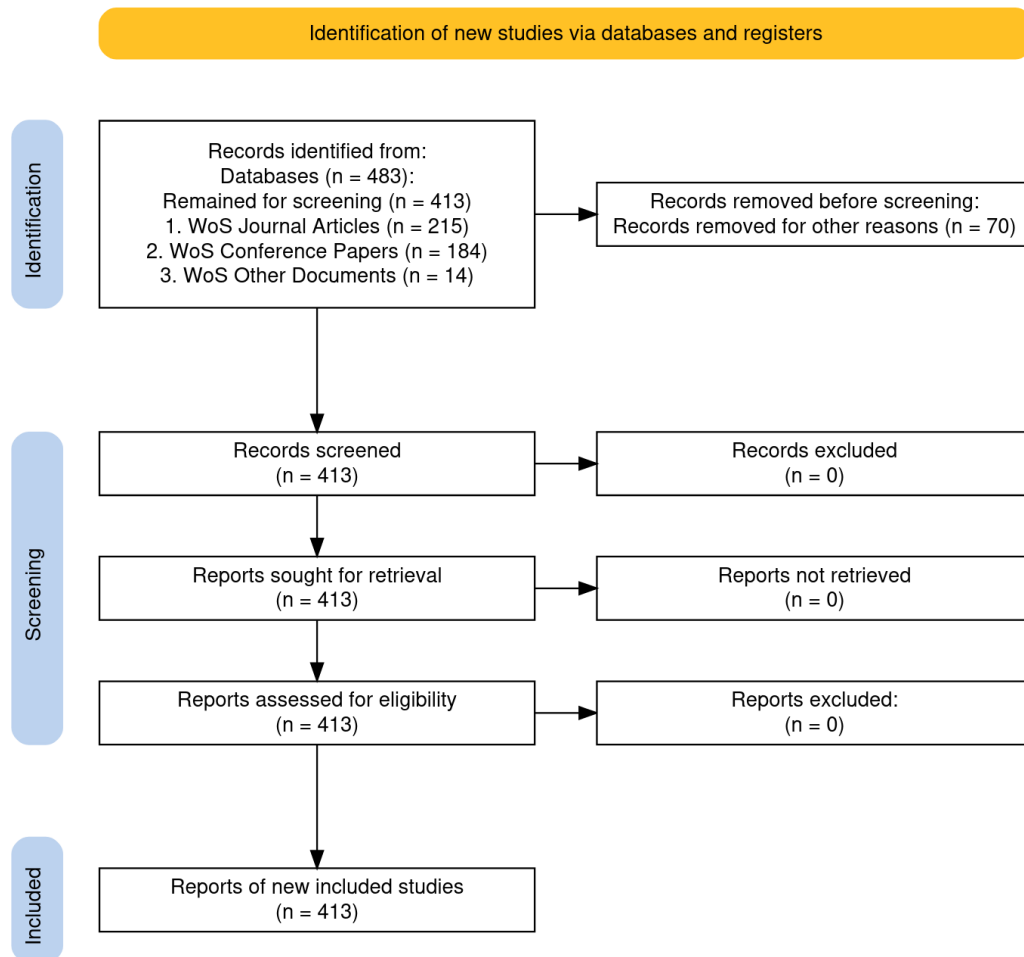


Figure 1. PRISMA flow diagram of the bibliographic study

The search terms included “electronic invoicing” or “e-invoicing”, “e-invoice”, and “electronic invoice”. For instance, the query in WoS was formulated as: TOPIC: (“e-invoice”) OR TOPIC: (“e-invoicing”) OR TOPIC: (“electronic invoicing”) OR TOPIC: (“electronic invoice”). In WoS, these search terms yielded 483 papers, including conference proceedings,

book chapters, and journals. After filtering for conference proceedings and journals and focusing on English-language documents, 413 items remained in the set. The included items thus present a systematic analysis of e-invoicing research, including records with primary focus in other fields and dealing with e-invoicing and relevant technologies only secondarily. Journal articles (n = 215) dominate the type of documents published so far in the field, followed by conference papers (n = 184) while other documents were just 14.

The following research questions have been formulated to inform the research directions: How has e-invoicing research progressed over time? Who are the most relevant authors publishing in e-invoicing research? What are the most relevant affiliations? What are the most relevant fields of study? In which Web of Science indexes were the publications included? What are the most globally cited documents in the e-invoicing domain?

3. Results

The results are organized according to the research questions addressed in the study, aimed at providing a multifaceted comprehensive understanding of the research focus.

3.1. Q1. How Has E-Invoicing Research Progressed Over Time?

To understand the research landscape of electronic invoicing and how the field has evolved, two analyses have been conducted—annual scientific production and citations per year to gauge the progress made over the years. The data indicate that research in the field of electronic invoicing began in 1994 with just one article published that year. Since then (from 1994 to the current year of 2024), there have been 413 publications, including primary journals (215 articles) and conferences (184 conference papers). Figure 2 shows a general rise in article production from the last 25 years from 2000 to 2024.

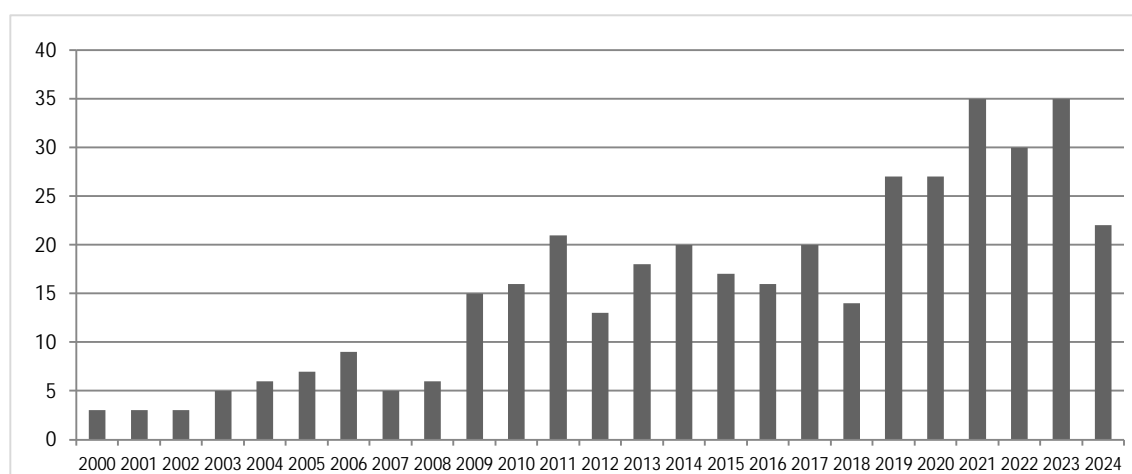


Figure 2. E-invoicing-related research publications over time between 1/2000 and 9/2024

Despite this, there was a notable increase in interest in electronic invoicing between 2008 and 2009, with significant growth observed between 2018 and 2019. Regarding the number of scientific articles produced, the most productive years were 2021, and 2023, both with 35 documents. On average, the annual production of electronic invoicing scientific papers increases is a median of 16 papers per year.

3.2. Q2. Who Are the Most Relevant Authors Publishing in E-Invoicing Research?

To reveal prolific and relevant authors in the field of electronic invoicing, author analysis has been conducted from two perspectives—the number of documents per author and the number of citations per author. Regarding the number of documents published, our results show the top 14 authors of 1277 entries in the field, with Cha, S.C., Gusev, M., Kreuzer, S., and Penttinen, E., being the leading authors, each with four documents whereas Bernius, S., Dias, E. M., Joung, Y.J., Kiroski, K., Kostoska, M., Li, W. G., Magdalenic, I., Prieto-Alhambra, D., Sharma, S., Tseng, Y. C. published three documents, as summarized in Table 1.

Table 1. The most relevant authors publishing in e-invoicing research

Authors	Record Count	% of 413
Anonymous	4	0.969
Cha, S. C.	4	0.969
Gusev, M.	4	0.969
Kreuzer, S.	4	0.969
Penttinen, E.	4	0.969
Bernius, S.	3	0.726
Dias, E. M.	3	0.726
Joung, Y. J.	3	0.726
Kiroski, K.	3	0.726
Kostoska, M.	3	0.726
Li, W. G.	3	0.726
Magdalenic, I.	3	0.726
Prieto-Alhambra, D.	3	0.726
Sharma, S.	3	0.726
Tseng, Y. C.	3	0.726

3.3. Q3. What Are the Most Relevant Affiliations?

According to Table 2, the three leading institutions in the field of electronic invoicing are the Goethe University Frankfurt, National Taiwan University, and Universidade de Sao Paulo. All of them published 6 articles. The Goethe University Frankfurt has more than 50 partnerships globally, and authors from the university have been active in electronic invoicing projects.

Chen et al. (2015) showed an integrated e-invoice system in Taiwan. Lian (2015) devoted crucial factors for cloud-based e-invoice service adoption in Taiwan. Joung et al. (2014) presented an overview of motivations, deployment, and assessment of Taiwan's e-invoicing system. Matus et al. (2017) wrote their paper 7 years ago when Brazil began planning to deploy electronic invoice infrastructure based on the formulated national e-business strategy. Although these institutions collaborate closely, international collaboration remains limited, indicating a gap for future researchers to address. Figure 3 shows the cities hosting institutions most involved in e-invoicing research.

Table 2. The most relevant affiliations (4 and more articles)

Affiliations	Record Count	% of 413
GOETHE UNIVERSITY FRANKFURT	6	1.453
NATIONAL TAIWAN UNIVERSITY	6	1.453
UNIVERSIDADE DE SAO PAULO	6	1.453
AALTO UNIVERSITY	5	1.211
AUTONOMOUS UNIVERSITY OF BARCELONA	5	1.211
INST CATALA SALUT	4	0.969
NATIONAL TAIWAN UNIVERSITY OF SCIENCE TECHNOLOGY	4	0.969
UNIVERSITY OF BARCELONA	4	0.969
UNIVERSITY OF OXFORD	4	0.969
UNIVERSITY OF ZAGREB	4	0.969
UNIVERSITY OF ZARAGOZA	4	0.969

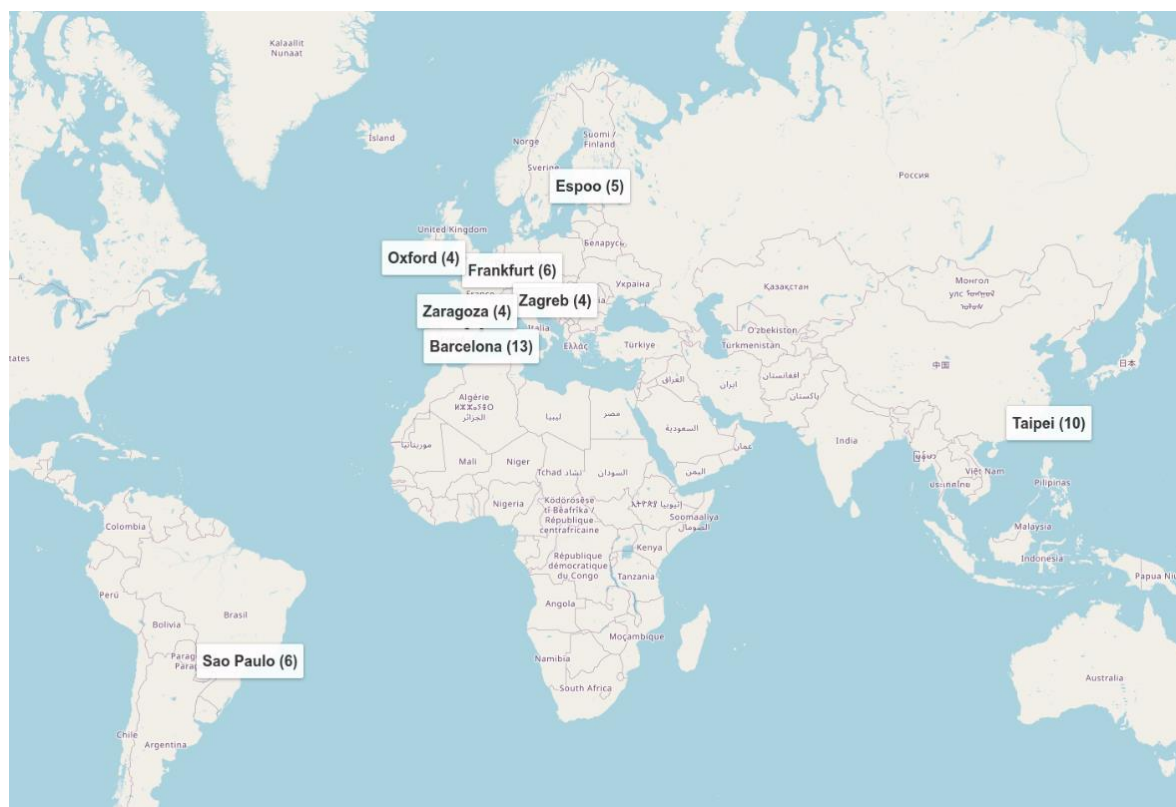


Figure 3. Cities with the main institutions engaged in e-invoicing-related research (publication counts between 1/2000 and 9/2024)

3.4. Q4. What Are the Most Relevant Fields of Study?

Table 3 shows that the fields in which most e-invoices are published are not financial management, but computer science. Minor fields are, for example, law, political science, or public economics.

Table 3. The most relevant categories

Web of Science Categories	Record Count	% of 413
Computer Science Information Systems	97	23.487
Computer Science Theory Methods	62	15.012
Engineering Electrical Electronic	61	14.770
Computer Science Interdisciplinary Applications	51	12.349
Computer Science Artificial Intelligence	47	11.380
Management	41	9.927
Business	33	7.990
Economics	27	6.538
Information Science Library Science	27	6.538
Computer Science Software Engineering	23	5.569
Telecommunications	22	5.327
Operations Research Management Science	14	3.390
Business Finance	11	2.663
Law	11	2.663
Political Science	11	2.663
Social Sciences Interdisciplinary	10	2.421
Energy Fuels	9	2.179
Education Educational Research	8	1.937
Engineering Multidisciplinary	8	1.937
Materials Science Multidisciplinary	8	1.937
Physics Applied	8	1.937
Engineering Civil	7	1.695
Engineering Industrial	7	1.695
Multidisciplinary Sciences	7	1.695
Public Administration	7	1.695

3.5. Q5. In Which Web of Science Indexes Were the Publications Included?

As depicted in Table 4, most publications (n = 161; 39%) were in conference proceedings (CPCI-S), followed by Science citation index expanded (SCI-EXPANDED), Emerging sources citation index (ESCI), Social science station index (SSCI), and Conference proceedings citation index – social science & humanities (CPCI-SSH).

Table 4. Web of Science indexes

Web of Science Index	Record Count	% of 413
Conference Proceedings – Science (CPCI-S)	161	38.983
Science Expanded (SCI-EXPANDED)	108	26.150
Emerging Sources (ESCI)	89	21.550
Social Sciences (SSCI)	61	14.770
Conference Proceedings – Social Science & Humanities (CPCI-SSH)	44	10.654

3.6. Q6. What Are the Most Globally Cited Documents in the E-Invoicing Domain?

Citation-based bibliometric analysis is a widely used way to assess an author's productivity and impact through quantity, quality, and structural indicators. Quantity shows the volume of academic works produced within a specified period. Quality measures the author's performance based on the H-index and other quality indicators. At the same time, the structure combines the author's connections and collaboration within and beyond publications and research domains. The authors' production, performance, and presentation are critical for the academic community, organizations, and society at large, as they indicate the metrics used in funding decisions, appointments, and promotions of researchers. It also facilitates the citation frequency of researchers and increases the author's visibility. Table 5 presents the summary results of the main citation characteristics for the research data set.

Table 5. The main characteristics of citations

Results found	413
Sum of the Times Cited	2295
Average Citations per Item	5.56
h-index	23

The most globally cited document in the electronic invoicing research domain is titled: "The Effect of Environmental Concern and Skepticism on Green Purchase Behavior" by Albayrak et al. (2013) with 197 citations. This leading paper was published in *Marketing Intelligence & Planning*, a journal with an impact factor of 2.164 as of 2020. The second most globally cited document is titled: "Critical Factors for Cloud-based e-invoice Service Adoption in Taiwan: An Empirical Study" authored by Lian (2015), which recorded 127 citations. The outlet of this paper is the *International Journal of Information Management*, with an impact factor of 14.098. The journal has been ranked number one out of 86 in information science and library science. Followed by 116 citations for the document „Robustness of Offline Signature Verification based on Gray Level Features“, in *IEEE Transactions on Information Forensics and Security*, by Ferrer et al. (2012). The fourth most globally cited document is "Practices as markets: Value co-creation in e-invoicing" by Korkman (2010), which received 72 citations. The paper was published by the *Australasian Marketing Journal (AMJ)* with an impact factor of 3.29.

According to analysis of the keywords in their title and abstract, among 29 most cited papers with at least 20 citations each only 13 papers dealt with e-invoicing primarily, whereas the remaining 16 most-cited papers' primary focus was different. Furthermore. The 29 most cited papers' publication average year was 2012. Only two recent papers (less than 5 years old), dealing mainly with e-invoicing received at least 20 citations: "E-governance, Accountability, and Leakage in Public Programs: Experimental Evidence from a Financial Management Reform in India" (Banerjee et al., 2020) and "Digitalization to improve tax compliance: Evidence from VAT e-Invoicing in Peru" (Bellon et al., 2022).

Some of the leading authors published in high-impact journals. Although the impact factor is very relevant, in this study, a lower impact factor (2.164) commands more citations

than a higher impact factor (14.098). While it is challenging to justify why a scholar who has published ten articles since 2013 in the field of electronic invoicing might have a smaller number of citations compared to those who published only one article in 2018, various reasons could be responsible. A breakthrough work may for its merit initially get more citations, driving further attention, eventually becoming a cornerstone in its area. On the contrary, practices such as not citing an article that influenced an author or citing just marginally relevant sources distort the results. These are among the reasons why publication counts and citation counts for measuring scholars' impact have received criticism (Singh et al., 2021).

4. Discussion

The study explored the research landscape of electronic invoicing using a qualitative bibliometric approach. The goal was to shed light on recent developments in the field and to analyze the evolution of studies on electronic invoicing. Investigating electronic invoicing literature is crucial for establishing research excellence through quantitative analysis, which provides reliable evidence and benchmarks for the field (Veselá & Radiměřský, 2014).

The analysis covered 413 papers published between 1994 and 9/2024. The peak in the number of publications in 2023 indicates a growing scholarly interest in advancing the field, suggesting a potential for steady growth in article production. The finding supports Marinagi et al. (2015) forecast of widespread global adoption of electronic invoicing by 2025 however further research would have to be conducted for a more affirmative conclusion. Even if e-invoicing is becoming adopted more widely globally, it does not necessarily have to match the development in individual countries (Kuběnka et al., 2024).

To identify prolific contributors in the field of electronic invoicing and assess their impact, the number of publications per author and the number of citations per author have been examined. The top 13 authors from a total of 1,277 entries—Cha, S. C., Gusev, M., Kreuzer, S., and Penttinen, E.—each co-authored just four documents. Additionally, Bernius, S., Dias, E. M., Joung, Y. J., Kiroski, K., Kostoska, M., Li, W. G., Magdalenic, I., Prieto-Alhambra, D., Sharma, S., and Tseng, Y. C. each published three documents. Neither a globally dominant author nor a small group of leading authors have been identified, giving more opportunity to researchers worldwide.

The top three institutions in the field of electronic invoicing are Goethe University Frankfurt, National Taiwan University, and Universidade de São Paulo, each contributing six articles. Unsurprisingly, Goethe University Frankfurt leads in relevant affiliations, given its over 50 global partnerships and the active involvement of its researchers in electronic invoicing projects. However, the international cooperation in e-invoice research is still limited.

The most e-invoice articles analyzed belong in the field of computer science and deal mainly with e-invoicing technical aspects. Surprisingly, only a limited number of articles from the fields of law, political science, or public economics were present in the dataset, hinting at a potentially fruitful area for investigating e-invoicing from this perspective or applying a multidisciplinary approach.

This study investigated Web of science via the Conference Proceedings Citation Index – Science (CPCI-S), Science Citation Index Expanded (SCI-EXPANDED), Emerging Sources Citation Index (ESCI), Social Science Citation Index (SSCI), and Conference Proceedings Citation Index – Social Science & Humanities (CPCI-SSH) with the most publications (n = 161) listed in conference proceedings (n=161, which was 39%). The variability in citation counts across years may be attributed to the field's ongoing maturation and the relatively limited research activity from industry players, despite the benefits of electronic invoicing (Chang et al., 2020). However, the reasons for a relatively low presence of articles in high-impact journals and relatively low level of citations in high-impact journals compared to lower impact journals might be further investigated.

The most cited works, all 9+ years old, include Albayrak et al. (2013) on green purchase behavior, Lian (2015) on cloud-based e-invoicing in Taiwan, Ferrer et al. (2012) on signature verification, and Korkman et al. (2010) on value co-creation in e-invoicing. All the most widely cited articles approached the topic of e-invoicing in combination with other relevant information technology or solutions. Thus, it might be reasonable to focus today's e-invoicing research on similar integration opportunities such as with robust business data processing automation and integration B2B EDI systems, in governments' tax evasion prevention systems, QR payment systems, modern IS architectures, or AI-based automation or fraud detection and prevention solutions.

This study used the Web of Science (WoS) database, which provides a representative view of electronic invoicing research but may not be exhaustive due to defined search boundaries. Future research could use additional database like Scopus, Google Scholar or FT50 journals to include potentially missed materials such as research reports and working papers. The study suggests several future research directions: investigating factors limiting scientific production, exploring e-invoicing implementation in different contexts, examining the influence of e-invoicing on governance and accountability, and evaluating the role of government and policymakers in adoption.

5. Conclusions

The systematic study of 413 conference and journal papers over the past two decades in electronic invoicing indicated that the field is growing, with a peak in publications in 2021 and 2023 suggesting increasing interest, conducted by a diverse group of authors, particularly from Germany, Taiwan, and Brazil. Despite the field's increasing importance, the number of articles is still relatively low, namely in non-IT fields such as law, political science, or public economics. More multidisciplinary research is needed to address major gaps and explore new opportunities and challenges. Future research should consider not just the potential benefits of e-invoicing, synergies with other information technologies such as EDI, tax evasion prevention systems, QR payment systems, or AI-based automation or fraud detection and prevention solutions, but also study regional disparities, especially in Australia and Africa, and focus on compliance, security, and VAT aspects of emerging electronic invoicing ecosystems.

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Hybrid Management in Healthcare: Lessons Learned from Case Studies in Czech Hospitals

Petra HOSPODKOVÁ^{1,2*} and Martina CAITHAMLOVÁ¹

¹ Czech Technical University in Prague, Kladno, Czech Republic; hospopet@fbmi.cvut.cz; caithmar@fbmi.cvut.cz

² Czech University of Life Sciences Prague, Prague, Czech Republic; hospodkova@pef.czu.cz

* Corresponding author: hospopet@fbmi.cvut.cz

Abstract: Hybrid management, which combines traditional methods with modern technologies, is vital for optimizing healthcare delivery, especially in the Czech Republic, where a significant staffing crisis demands greater efficiency and productivity. This paper explores the impact of hybrid management on the efficiency and quality of care in Czech university hospitals. The research includes a comprehensive literature review and empirical analysis through two case studies. These studies employed tools such as process mapping, surveys, and in-depth interviews with employees. The interviews were analyzed using content analysis and the software MAXQDA to identify key improvement areas. The findings demonstrate that hybrid management led to a substantial reduction in time spent on tasks, a decrease in errors, and a notable increase in staff satisfaction. These results highlight the importance of integrated care and underscore the necessity for improved resource management and ongoing innovation. The study emphasizes the crucial role of healthcare quality in fostering a satisfying and productive workforce, which in turn contributes to the development of human capital.

Keywords: hybrid management; healthcare efficiency; quality of care; Czech university hospitals; process analysis

JEL Classification: I1; I190

1. Introduction

The healthcare sector is increasingly recognizing the need for adaptive and flexible management strategies to address modern healthcare delivery's complexities. Hybrid management, a concept that integrates traditional management models with digital tools and innovative practices, provides a flexible approach that can improve organizational efficiency, staff productivity, and patient care quality in response to the dynamic healthcare environment (Awad et al., 2021). This approach not only combines diverse leadership styles but also utilizes the expertise of hybrid professionals. These individuals bridge clinical and managerial roles within healthcare organizations, facilitating seamless alignment between clinical priorities and organizational goals.

Three primary aspects of hybrid management in healthcare include: balancing professional and administrative domains, integrating clinical and operational expertise, and combining strategic oversight with tactical management. Byrkjeflot and Jespersen (2014),

identify these frameworks as critical for aligning clinical autonomy with organizational objectives, thus enabling healthcare organizations to respond more effectively to complex challenges. Hybrid leadership, characterized by a blend of transformational, transactional, and participatory approaches, plays a vital role in creating inclusive, adaptable environments that can withstand shifts in technology and workforce expectations. Sparks and McCann (2023) emphasize that hybrid leadership styles, which merge transformational, transactional, and democratic elements, are effective in fostering inclusion within healthcare workplaces. Their research highlights that such leadership styles enhance a sense of belonging and individual recognition among employees, which are essential for building inclusive and collaborative work environments. Additionally, adaptable leadership strategies are crucial for managing the increasing diversity within healthcare teams and encouraging a culture of innovation and teamwork in patient care (Volland et al., 2017). Integrating clinical knowledge with operational decision-making has also become a valuable feature of hybrid management in healthcare. Giasson (2019) argues that hybrid project management, which combines structured management practices with flexible methods, is especially useful in streamlining healthcare operations while adapting to emerging challenges. This approach allows for more responsive decision-making processes by bridging clinical workflows with administrative demands, ensuring that organizational strategies support patient care priorities. Kirkpatrick et al. (2023) further explore this integration, demonstrating that blending clinical and managerial functions improves healthcare service delivery.

Recent knowledge-based systems have also been shown to enhance quality management in healthcare by allowing managers to better utilize combined clinical and administrative knowledge. Al Khamisi et al. (2017) introduced a new methodology for quality management that leverages hybrid systems, enabling improved data access and knowledge sharing among healthcare teams, which fosters more efficient operations and informed decision-making. The integration of technologies and data analytics within hybrid management frameworks has further transformed healthcare operations. These tools support healthcare leaders in making data-driven decisions that optimize resource allocation, reduce inefficiencies, and improve patient outcomes. For instance, Sartirana and Giacomelli (2024) provide a synthesis of the enabling conditions for hybrid professionalism, noting that the use of digital tools is essential in enhancing the effectiveness of hybrid professionals in healthcare settings. As healthcare institutions increasingly adopt technologies like electronic health records, telemedicine, and predictive analytics, the role of technologically adept managers who can interpret and effectively utilize this data becomes indispensable.

Despite its advantages, the implementation of hybrid management is not without challenges. Resistance to change, particularly among healthcare professionals who are accustomed to traditional management styles, can pose significant barriers. The initial costs associated with adopting new technologies and practices can also be substantial. Nonetheless, these challenges are often outweighed by the long-term benefits, including improved efficiency and patient care outcomes (Sartirana & Giacomelli, 2024). Studies indicate that clear communication and comprehensive training are essential for overcoming resistance to hybrid management practices and ensuring a smooth transition to more

integrated systems (Volland et al., 2017). Furthermore, the role of hybrid professionals in the public sector has been reviewed extensively, showing that their involvement is crucial in navigating the complexities of public healthcare management (Sartirana & Giacomelli, 2024).

In conclusion, hybrid management is a robust framework for addressing the multifaceted challenges of contemporary healthcare. By incorporating diverse leadership styles and leveraging the expertise of hybrid of hybrid management in optimizing healthcare processes and improving patient outcomes.

2. Methodology

The research methodology for this study follows the DMAIC framework (Gitlow et al., 2015), a structured, data-driven approach commonly used in process improvement (Mishra & Kumar Sharma, 2014; Tumasyan et al., 2022). The DMAIC framework is particularly well-suited for identifying inefficiencies and implementing effective changes in healthcare settings. Each phase of the DMAIC process was carefully applied to ensure a comprehensive analysis of the impact of hybrid management on efficiency and quality in Czech university hospitals.

2.1. Define Phase

The definition of the problems was based on a brainstorming session with the department's management and their long-standing dissatisfaction with key operational areas. In the table below, an overview derived from the Define phase is provided.

Table 1. Summary of define phase findings

Aspect	Endocrinology Department Case Study A	Logistics Department Case Study B
Characterization of Operations	Specializes in the diagnosis and treatment of hormonal disorders. High patient volume and complex healthcare delivery. The main challenge is reducing waiting times and optimizing patient and staff movements.	Focuses on inventory management, distribution of medications and medical supplies, and supplier coordination. The main challenges were optimising the processes of medical material procurement, optimising inventory levels, improving material flow, and minimising stock shortages.
Research Question 1	How can hybrid management reduce waiting times at the Endocrinology Department?	How can logistics be rationalized to reduce costs associated with inventory management?
Research Question 2	What steps can be taken to improve overall efficiency while maintaining care quality?	How can the distribution of medical supplies and medications be optimized to minimize delays and shortages?
Research Question 3	What are the main barriers to optimizing patient flows in this specific environment?	What technological and process innovations can improve the management of logistics operations in the hospital?

2.2. Measure Phase

During the Measure phase, various tools and methods were employed to quantify the current state of processes in both departments. The goal was to gather detailed data to

analyze existing inefficiencies and identify areas for improvement. The following methods were used:

Semi-structured Interviews:	Collection of Relevant Documents:	On-site Observation:
<ul style="list-style-type: none"> • 10 key employees (min. 2 years' experience, direct involvement in processes, holistic department knowledge). • Each interview lasted 35 minutes, recorded, and transcribed. • Focused on identifying challenges and improvement suggestions. 	<ul style="list-style-type: none"> • Gathered job descriptions, work processes, SOPs, inventory management, and stock level structures etc. • Provided insights into formal processes and workflows. 	<ul style="list-style-type: none"> • Conducted over 1 month. • Daily notes on logistical and clinical processes. • Real-time insights into operational inefficiencies.

Figure 1. Data collection tools in the measure phase

2.3. Analyze Phase

In the analysis phase, the aim was to use a combination of various tools to first uncover the specific factors influencing each problem, and then to identify the precise bottlenecks. This approach facilitated the proposal of potential improvements for addressing these issues.

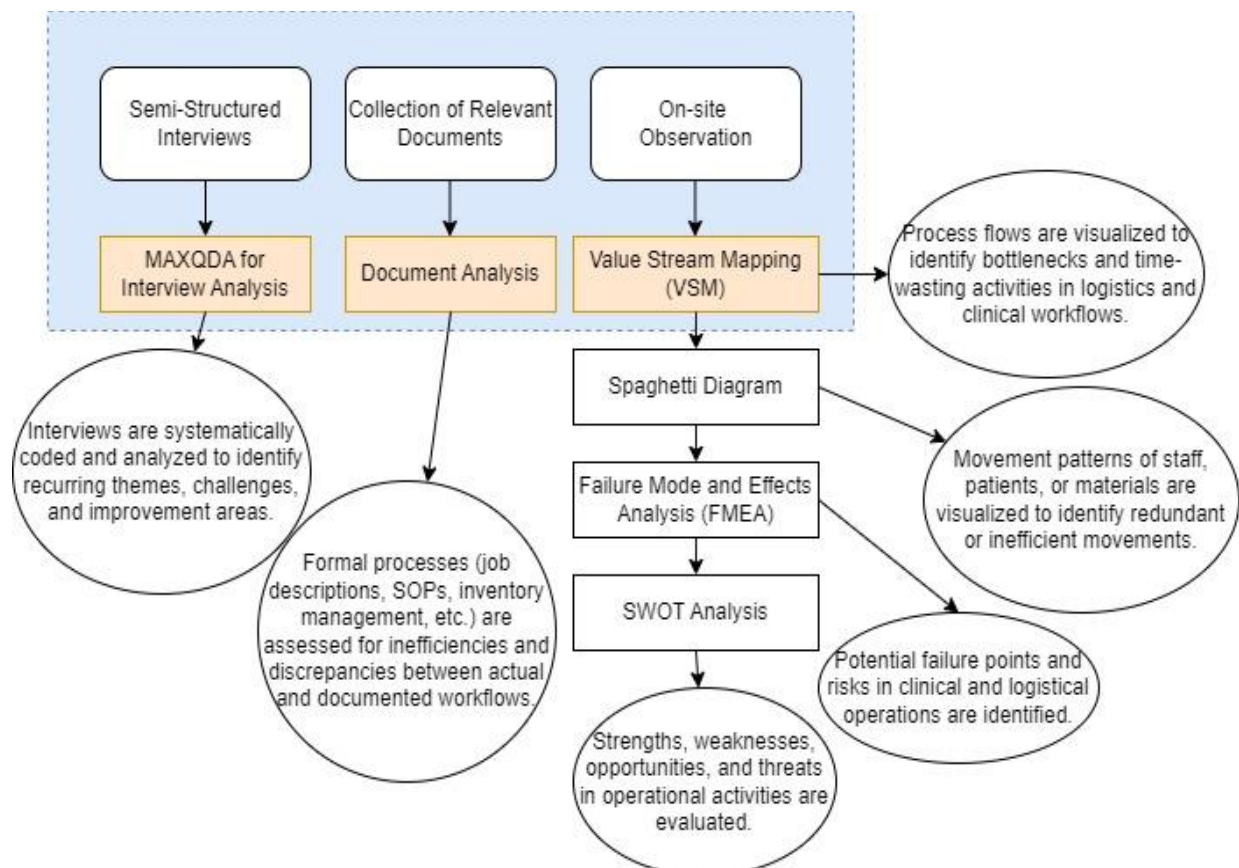


Figure 2. Data analysis tools in the analyze phase

2.4. Improve Phase

The improve phase involved developing and testing specific strategies to address the inefficiencies identified in the Analyze phase. This included:

- **Process Optimization:** Design to implement changes in inventory levels, material flows, and the integration of modern information technologies.
- **Pilot Testing:** Proposed improvements were tested in a controlled environment to assess their impact before full-scale implementation.

2.5. Control Phase

Finally, the Control phase focused on sustaining the improvements made during the previous phases. This involved:

- **Monitoring and Feedback Loops:** Regular monitoring of key performance indicators (KPIs) to ensure that improvements are maintained.
- **Standardization:** Formalizing new processes to ensure consistency in implementation across departments.
- **Training Programs:** Developed to ensure that all staff members are equipped to adhere to the new procedures.

3. Results

The results from the two case studies are presented separately, each aligned with the research questions posed during the Define phase and following the DMAIC methodology. The findings highlight specific issues, root causes, and proposed solutions, providing a detailed analysis of the impact of hybrid management on healthcare processes.

3.1. Define Phase

The main issues identified in the Endocrinology Department included long patient waiting times, inefficient use of resources, and suboptimal patient flow, which were directly linked to the existing management practices. The department was struggling to meet the increasing demand for its services while maintaining high standards of care. The key performance indicators (KPIs) were identified, these included Average Waiting Time (AWT), staff utilization (SU) as qualitative KPI and patient throughput (PT). The Logistics Department will focus on KPIs like Inventory Efficiency (IE), Order Fulfillment Time (OFT), which are key to managing inventory levels, avoiding stock-outs, and ensuring efficient supply chain operations.

Table 2. KPI defined

KPI	Formula/Qualitative measure	Endocrinology Department (Case A)	Logistics Department (Case B)
Average Patient Waiting Time (AWT)	$\Sigma(\text{Waiting Time per Patient}) / N$	Average time patients spend waiting between consultations and diagnostics	N/A
Staff Utilization (SU)	Staff Workload Balance (based on feedback and observational data)	Qualitative feedback on staff workload balance and resource use during patient care	N/A
Patient Throughput (PT)	Total Patients Served / Time Period	Number of patients handled efficiently within a specified timeframe	N/A
Inventory Efficiency (IE)	Total Value-Added Time/Total Lead Time $\times 100$	N/A	Efficiency of inventory flow between supplier, warehouse, and clinics
Order Fulfillment Time (OFT)	$\Sigma(\text{Time to Fulfill Orders})/N$	N/A	Time is taken to process and fulfil internal supply orders

3.2. Measure Phase

Key performance indicators (KPIs) were measured to establish a baseline for comparison after implementing hybrid management strategies.

Table 3. KPI measured

	Case Study A		
Research Question	KPI	Measured Value	Comment
V1	APWT	82 minutes	High waiting time, leading to patient dissatisfaction
V2	SUR	Underutilization during non-peak hours; Stress during peaks	Staff overwhelmed during busy hours, idle time during slower periods; errors and delays observed
V3	PT	130 patients/day	Low throughput, below department capacity
	Case Study B		
Research Question	KPI	Measured Value	Comment
V1	IE	78.67%	Moderate efficiency between supplier and warehouse
V2	OFT	142 min.	Long delays in order fulfillment for clinics

In Case Study A (Endocrinology Department), the performance indicators reveal substantial inefficiencies in patient flow and staff management. The Average Patient Waiting Time (APWT), recorded at 82 minutes, highlights significant delays between patient check-in and consultation, contributing to patient dissatisfaction and overcrowding. These delays are largely due to poor scheduling practices and inadequate resource allocation during peak times. The Staff Utilization Rate (SUR), assessed qualitatively through interviews and observations, demonstrated an uneven distribution of workload. During non-peak hours, staff experienced long periods of idle time, while during peak hours, they were overworked,

leading to stress and frequent errors in patient records. This imbalance reduced overall efficiency and created further delays in patient diagnostics. Additionally, Patient Throughput (PT) showed that the department was handling only 130 patients per day, below its potential capacity. The low throughput is primarily attributed to bottlenecks in patient flow caused by inefficient resources and staff allocation during high-demand periods. These findings suggest that improvements in staff scheduling, better alignment of resources with patient demand, and streamlined patient flow processes are essential to enhancing the department's operational efficiency and the quality of care.

In Case Study B (Logistics Department), the key performance indicators highlight critical challenges in supply chain efficiency and inventory management. The Inventory Efficiency (IE), measured at 78.74%, indicates that while most of the time spent in inventory processing adds value, there remains a significant proportion of time lost due to delays and non-value-adding activities, such as waiting for stock movements or transportation. The Order Fulfillment Time (OFT), with an average of 142 min. per order, underscores inefficiencies in the logistics processes, particularly in the time taken to fulfill internal supply orders. This slow fulfillment time causes delays in delivering medical supplies to the clinical departments, potentially impacting patient care. Together, these KPIs suggest that improving inventory management systems, optimizing the supply chain flow, and reducing delays in order fulfillment are critical for increasing the efficiency and reliability of the logistics department.

3.3. Analyze Phase

The analysis phase involved identifying the root causes of the inefficiencies. The following were identified as the primary contributors in table below.

Table 4. KPI analyzed

KPI	Root Cause	Analytical Tool Used	Key Findings (examples)
APWT (Case A)	Poor scheduling and misalignment of staff and patient flow	VSM, Spaghetti Diagram, Interviews	The Spaghetti Diagram showed patients crossing departments 5+ times, adding 25 minutes to the average wait time
			VSM revealed non-value-adding steps causing up to 40% idle time between consultations
SUR (Case A)	Uneven workload distribution between peak and non-peak hours	MAXQDA, Interviews, Document Analysis	The 45-minute idle time during non-peak hours; peak hours showed a 30% overwork rate, leading to documentation errors
			Document analysis revealed rigid staff allocation policies
PT (Case A)	Inefficiencies in patient flow and delays between procedures	VSM, SWOT, Spaghetti Diagram	Patients moved back and forth between diagnostic rooms, leading to a 20% decrease in daily throughput
			Average patient throughput was 130/day, below the expected 180/day capacity
OFT (Case B)	Excess material handling	VSM, SWOT, Document Analysis	Order fulfilment time averaged 142 min., with delays caused mainly by unnecessary material handling
			Document analysis indicated a lack of real-time tracking to the processing
IE (Case B)	Manual monitoring of stock by employees	FMEA, VSM	VSM showed a noticeable shortening of the process due to the implementation of barcode readers

This table and accompanying detailed examples provide a deeper, more quantitative, and specific analysis of the root causes, helping to link the problems defined by KPIs to concrete operational inefficiencies.

3.4. Improve Phase

In the following table, a summary of the measured KPIs after the implemented changes is presented, highlighting the improvements achieved as a result of these interventions.

Table 5. KPI improved

KPI	New Measured Value	Improvement	Comment
APWT (A)	45 minutes	Reduced by 37 minutes (45%)	Dynamic scheduling system reduced waiting time during peak hours.
SUR (A)	Balanced workload during shifts	Workload evenly distributed; errors reduced	Real-time data monitoring ensured an optimal balance between staff idle time and peak hours.
PT (A)	170 patients/day	Increase of 40 patients/day (30%)	Optimized patient flow and resource allocation improved throughput, and close to maximum capacity.
OFT (B)	142 min	Reduction of 13,5 min (10%)	Removing the excess material handling reduces the total time from 142 min to 128 min.
IE(B)	78.65 %	15 % increase in process efficiency	Due to the implementation of barcode scanners and the elimination of non-value-adding activities, process efficiency increased from 78.67% to 93.55%

1. Improvement Strategies for Hybrid Management (Case Study A):

- **Dynamic Scheduling System**
Hybrid Tool: The dynamic scheduling system integrated both automated scheduling algorithms and manual oversight by department managers. The software monitored real-time patient arrivals and dynamically adjusted appointment times, ensuring a smoother patient flow. During peak hours, manual interventions allowed the management to allocate additional staff where needed.
- **Real-Time Staff Utilization Monitoring**
Hybrid Tool: Real-time staff monitoring systems combined with digital tracking tools with manual check-ins. Automated data was collected on staff activity, including time spent on consultations, breaks, and idle periods. Department managers were able to adjust staff allocation throughout the day, based on live data feeds, to address workload imbalances.
- **Optimized Patient Flow with Resource Allocation**
Hybrid Tool: Patient flow management was improved by integrating digital tools that managed room assignments and patient routing with manual oversight by department coordinators. Automated alerts notified staff when rooms or equipment became available, allowing patients to be routed more efficiently between consultations and diagnostics.

2. Improvement Strategies for Hybrid Management (Case Study B)

- Minimization of the Logistic Costs

Recent times have placed greater demands on the supply of healthcare facilities. The consumption of medical supplies is growing, the costs associated with supply are increasing and healthcare facilities are trying to minimize these costs. One of the ways is to analyse and optimise supply-related processes, manage material flows, design measures that could bring cost savings, consistently classify inventories and integrate information systems. A study carried out in a teaching hospital shows that reducing the time-consuming nature of processes would reduce staffing and thus the number of staff in the medical consumables warehouse.

- Effective inventory management

However, the main objective of hospital logistics within the material flow is to ensure sufficient stocks of the necessary goods to ensure that materials are available in the right quality, in the right quantities, at the right time and in the right places to enable quality patient care. An essential element to ensure efficient logistics processes is recording, management and control of inventory. Computerisation of processes is essential to ensure adequate stock control and record keeping. For automatic identification based on optical scanning, barcodes are the most useful and still the cheapest method. Barcode scanners were also included in the design of the rationalisation of the logistics processes within the medical consumables warehouse of the university hospital. Another proposal is the acquisition of RFID technology. However, RFID technology also allows for expiry notifications, stock quantity control and automatic purchase requests for replenishment. RFID technology could therefore lead to faster logistics processes, reduced manual work, as well as greater accuracy and elimination of error. A hybrid solution combining barcodes and RFID technology is also possible

3.5. Control Phase

All implemented processes were closely monitored for one month following their introduction to ensure their effectiveness and sustainability. However, it was found that a longer observation period is required to identify potential weaknesses and perform further optimizations. Ongoing data collection and analysis must be carried out to continuously improve and adapt these processes to changing conditions, ensuring long-term quality and efficiency.

In the case of study B, it would be desirable to completely overhaul the entire information system. However, the development and implementation of a comprehensive new system represent a multi-year project associated with significant financial costs. Therefore, gradual modernization of existing processes is preferred, for example, through the implementation of RFID technology or barcode scanning, optimizing logistics and inventory management without immediately burdening resources with a large investment.

4. Discussion

The healthcare sector in the Czech Republic faces several significant challenges, including an aging population, increasing life expectancy, rising healthcare costs, and limited funding sources (Český statistický úřad, 2022). The OECD has repeatedly highlighted these issues in its reports (OECD, 2023), and healthcare facility managers are under pressure to maximize resource efficiency while maintaining high-quality care. Hybrid management, which integrates innovative technologies and optimized processes, represents one pathway toward achieving these goals. Research demonstrates that operational efficiency can be significantly improved by embedding technology within healthcare settings, as supported by findings from other scholars, including Ong and Vigonte (2024) and Awad et al. (2021).

In this study, two case studies in Czech university hospitals—focused on logistics and endocrinology—demonstrated that hybrid management leads to measurable improvements in healthcare delivery. One case study emphasized logistics optimization, an area recognized as a substantial cost driver in hospitals, often second only to personnel costs (Volland et al., 2017). In the university hospital under study, logistics costs were the highest operational expense in 2023, underscoring the importance of targeting logistics for improvement. De Vries (2011), who highlights material flow management as a key area for cost containment. Digitalization and process optimization in logistics were shown to improve inventory control, reduce stockouts, and streamline logistics processes overall.

Several studies, such as those by Rocha and Rego (2023) and Khurana et al. (2013), have found that digitizing inventory processes improves logistical efficiency. In this study, we incorporated barcode scanning technology to enhance material tracking and reduce handling time. Similar initiatives have been proposed in the literature, with Coustasse et al. (2013) suggesting that RFID technology could further improve the precision and efficiency of inventory management. Indeed, Regattieri et al. (2018). also report that reorganizing inventory systems can reduce material handling times. This study supports these findings, with our proposed reorganization of the university hospital's inventory layout, reducing order processing times from 142 minutes to 128 minutes and improving efficiency by 15%.

Another critical aspect of hybrid management is overcoming resistance to change, which we identified as a barrier in the logistics department. Employee reluctance to adopt new systems was compounded by high initial costs, especially for comprehensive technology solutions like RFID. Sartirana and Giacomelli (2024) also cite these challenges, noting that while RFID technology offers long-term benefits, the upfront investment and change management efforts can be daunting for healthcare organizations. In light of these findings, a phased implementation approach is recommended, starting with barcoding technology and gradually introducing RFID over time. This phased approach enables cost management and allows employees to adjust incrementally to new processes.

The second department analyzed was the endocrinology department, chosen based on discussions with hospital management. Here, hybrid management was applied to address patient flow inefficiencies, long waiting times, and suboptimal resource use. Process management tools, as recommended by Brancalion and Lima (2022), were employed to

reduce patient wait times, achieving a reduction from 45 minutes to 32 minutes. This improvement was achieved through dynamic scheduling and optimized staff allocation, resulting in better capacity utilization and increased care accessibility. The study by Abdalkareem et al. (2021) also addresses similar benefits of hybrid management for patient scheduling and admissions, validating the effectiveness of these approaches.

In summary, the two case studies underscore the potential of hybrid management to enhance efficiency, quality, and staff satisfaction within Czech university hospitals. However, successful implementation depends on addressing both technological and human factors. Ensuring clear communication, comprehensive training, and gradual integration of new tools can help mitigate resistance to change, as supported by studies such as those by Volland et al. (2017). Additionally, a strategic approach to technology adoption—one that balances cost and impact—will be essential for sustainable improvements. The role of hybrid professionals, who bridge clinical and administrative expertise, is crucial in this regard, as their dual perspective helps integrate clinical needs with organizational strategies.

Ultimately, hybrid management offers a robust framework for addressing the multifaceted challenges of modern healthcare, providing pathways for improved care delivery and resource management. Future studies should explore the long-term impact of hybrid management on organizational culture, patient outcomes, and financial performance. Examining its scalability across different hospital environments and adaptability in non-hospital contexts would be valuable. Additionally, longitudinal research could capture long-term benefits and challenges. This study serves as a foundational investigation into hybrid management's role in Czech university hospitals and highlights key areas for further research and practical application.

5. Conclusions

This study demonstrates that hybrid management, which combines traditional methods with modern technological tools, can significantly enhance both efficiency and quality in healthcare settings. Through the analysis of two case studies in Czech university hospitals, it was observed that hybrid management approaches led to notable improvements in patient flow, staff utilization, and resource management. The dynamic scheduling and real-time monitoring systems reduced waiting times and improved staff workload distribution, while optimized logistics processes minimized delays and enhanced inventory management. Despite these improvements, the results indicate that further long-term observation and continuous refinement are essential for sustaining these benefits. Additionally, in the case of logistics management, a comprehensive overhaul of the information system is recommended, although this represents a multi-year project with considerable financial implications.

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SMEs in the Czech Republic and Their Practices in Implementing Change – Qualitative Analysis Using Structured Interviews

Lukáš KLARNER*, Petr ŘEHOŘ, Jaroslav VRCHOTA and Monika MAŘÍKOVÁ

University of South Bohemia in České Budějovice, České Budějovice, Czech Republic; klarnl00@ef.jcu.cz; rehor@ef.jcu.cz; vrchota@ef.jcu.cz; marikova@ef.jcu.cz

* Corresponding author: klarnl00@ef.jcu.cz

Abstract: This paper focuses on change management in small and medium-sized enterprises (SMEs) in the Czech Republic, in particular on the implementation of technological innovations related to Industry 4.0. The qualitative research involved structured interviews with ten representatives of SMEs from different sectors and sizes. The results revealed that the approach to change management is influenced by the size of the enterprise: medium-sized enterprises use project management, while smaller enterprises often apply ad-hoc approaches. Employee resistance, costs and technical barriers are key barriers. The study highlights the importance of communication, employee involvement and pilot testing in implementing change. Based on the findings, a seven-phase strategic framework was developed that includes status analysis, communication, employee engagement, visioning, pilot testing, implementation support, and anchoring change. This approach enables effective change management and supports the long-term competitiveness of SMEs.

Keywords: change; change management; SMEs; change model; Industry 4.0

JEL Classification: M00; M10; O31

1. Introduction

Change management is one of the management disciplines that today's dynamic environment is increasingly demanding. This is because it not only helps to introduce new elements into the business, but also enables the effective implementation of processes, corporate culture or organizational structure (Năstase et al., 2024). The process of change implementation involves a wide range of activities such as planning, communication, employee involvement in the implementation of the change, all of which of course ends with its implementation and subsequent monitoring (Mudjissatyo et al., 2024). However, it is important to note that change does not only affect the internal environment of the organization, but also serves the external partners of the company (Tryczak et al., 2024).

The primary reason for the growing interest in change management knowledge is currently the trend of Industry 4.0, also known as digital transformation (Ba et al., 2024). The importance of change management in the implementation of modern technologies is quite crucial and plays a significant role in implementation (Monferdini & Bottani, 2024).

Within change management, there are countless models to assist companies in their effective implementation. These models typically include the Lewin model (González et al., 2022), Kotter's 8-step model (Ravi et al., 2022), McKinsey 7S (Odeh, 2021) or the ADKAR model (Jaaron et al., 2022). However, it is also possible to encounter a variety of other existing models that do not necessarily focus on the entire change process, but only offer solutions to selected problems associated with change. These models are PDCA (Zhong et al., 2023), Bridges' transition model (Miller, 2017) or Satir's growth model (Leung et al., 2019).

However, along with the increasing pressures on businesses, there is also a growing need for continuously improving change models and creating new ones that can reflect the current needs of the market, organizations and society. Often, existing models are innovated for specific selected industries or situations, as Chaabi (2022) points out in the case of the ADKAR model; one can also find innovative approaches to using Lewin's model (Hatoum et al., 2021) or a completely different approach to adjusting models, as Hänselmann (2023) points out. However, it is not an exception that new approaches are defined, as shown by Grynko et al. (2024) in the example of the hotel industry, also approaches that only define new possible variables affecting organizational change can be found, as in the case of Elsaman (2023).

A focus on SMEs is very common. In this case, a number of areas are observed, such as employees' attitudes and attitudes towards change (Karácsony et al., 2023), this category of companies' attitudes towards innovation (Mladenova, 2024) or mapping Industry 4.0 technologies to facilitate their implementation in SMEs (Jafarzadeh et al., 2024).

2. Methodology

The main objective of this paper is to find a basic strategic framework according to which it would be possible to implement changes related to modern technologies in SMEs in the Czech Republic. This is the last part of the research, during which the empirical mapping of the area of change management and its relationship to modern technologies related to Industry 4.0, defining the basic barriers, causes of implementation and gaining an overview of how enterprises perceive this current challenge. More specifically, the research was conducted in three phases: (1) Empirical mapping of change management issues in SMEs and their relationship to modern technologies, (2) Identification of the main barriers and factors influencing the implementation of technological change, (3) Formulation of a strategic framework for change management using qualitative analysis. The same qualitative methodological approach within the research is not exceptional, even in terms of sample size, as reported by Calheiros-Lobo et al. (2024) or Fernandes et al. (2024). Based on the literature review and preliminary analysis of corporate approaches, the following research questions were identified throughout the whole research. First one was "What are the main factors influencing the implementation of technological innovation in Czech SMEs?" This one was followed by "What barriers do enterprises most often experience when implementing change?" Third research question was "What best practices are used by successful enterprises to effectively manage change?" The answers to these research questions were an integral part of the research, with the answers to the third question only being obtained during the qualitative analysis. Integral part of the research was a questionnaire survey. The data needed

to assess these objectives was collected through an online questionnaire survey that ran from October 2023 to January 2024, with a total of 240 respondents, all of whom were representatives of small and medium-sized enterprises (SMEs) across a range of sectors. Prior to the actual data collection, the questionnaire was validated through a pilot survey in which 20 entrepreneurs participated. These practitioners provided feedback on which adjustments were made - the wording of three questions was refined and the response scales for five others were modified. The questionnaire itself contained 18 questions, four of which were used to identify the business (e.g. by business ID, size, age and sector), while the remaining 14 focused on the use of modern technology and perceived barriers. Ten questions had a closed-ended structure, while four allowed for open-ended responses. The structure of the enterprises involved in the research was observed mainly from two perspectives - size and sector. In terms of size, micro enterprises had the largest share, followed by small and medium enterprises and the lowest share was for enterprises with no employees. In terms of sector, manufacturing enterprises were the most represented, followed by retail trade and professional, scientific and technical activities. The breakdown by industry followed the CZ-NACE structure. To check the statistical quality of the sample, the Kolmogorov-Smirnov test (Lopes, 2011) was used to observe the statistical representativeness of the data. The Shapiro-Wilk test (Ghasemi & Zahediasl, 2012) was also applied to check the normality of the data, and Cronbach's alpha (Bonett & Wright, 2015) was examined to determine the internal consistency of the data. Ordinal logistic regression (Liang et al., 2020), Kruskal-Wallis test (Ostertagová et al., 2014), PERMANOVA test (Anderson, 2017) and Dunn test (Dinno, 2015) were used to find out the specific effects or differences between categories. The main findings of the data were that attitudes to technological change vary based on the size of the business and that the most significant barrier was the problem of securing funds. In general, however, communication and teamwork are the most critical problems in change management. The most essential differences in technological change are observed between medium-sized and micro enterprises and enterprises without employees.

The last step in this research was a qualitative investigation in SMEs, using structured interviews with representatives of this category. A total of 10 interviews ($n = 10$) were conducted during the months of September, October and December 2024. The battery of questions asked was based on the original questionnaire survey, as the aim of these interviews was to find the reasons why entrepreneurs and organizations in the SME sector behave in the way identified. Prior to the actual implementation of these interviews, a pilot survey was used to test the correct construction of the questions, and two groups of pilot respondents were approached - the first group were entrepreneurs themselves, and the second group were completely independent individuals who are not entrepreneurs. Both these groups provided suggestions for improvement as some questions were not clearly formulated and the answers might not yield the desired results. A total of 6 questions were modified in this way, 4 of which both groups agreed on.

After the interviews were transcribed, a thematic analysis was carried out, in which the respondents' answers were systematically coded according to predefined categories (e.g., barriers, implementation strategy, approach to employees). The use of thematic analysis

made it possible to identify recurring patterns in SMEs' approach to change and build a strategic framework for implementing technological innovations.

Each of the respondents answered the following 17 questions (see Table 1) and the specific structure of enterprises is then shown in Table 2.

Table 1. Used questions

Number	Question
1	How does your company approach change management? Do you have a system or method in place?
2	What major changes have you had to deal with in the last three years?
3	What barriers have you experienced in managing these changes?
4	What technologies do you currently use and how do they contribute to the effectiveness of the company?
5	How often do you introduce new technologies and what drives you to do so?
6	How do you select the technologies you introduce to the firm? Do you have a process for doing so?
7	How do you perceive the benefits of modern technology for your company?
8	Are there technologies that you would like to introduce but have not yet been able to?
9	How do your employees respond to new technologies?
10	How has technology affected the company culture?
11	How have technologies affected customer relationships?
12	Have you encountered any unexpected problems in the implementation process?
13	How do you finance the introduction of new technologies?
14	What is your plan for future digitization and automation?
15	How has technology affected the way you communicate within the company
16	How do you rate the overall impact of technology on your company?
17	Do you believe you observe a relationship between change management and Industry 4.0 in your business?

Table 2. Sample structure

Interview number	Industries	Size of the company
1	Energy	Small
2	Logistics	Small
3	Manufacture and sale of clothing	Medium-sized
4	IT	Micro
5	Pharmacy	Medium-sized
6	Production and sale of food	Micro
7	Automotive	Medium-sized
8	Agriculture	Small
9	Sale of furniture and decorations	Small
10	Agriculture	Medium-sized

As can be seen from Table 2, the sectoral spectrum of the enterprises represented is very broad. Both high-tech sectors (IT, Automotive or Pharmaceuticals) and traditional sectors (Retail, Logistics, Manufacturing) or Agriculture are represented. The sample includes 2 micro enterprises, 4 small organizations and 4 medium-sized enterprises.

3. Results

Within the results, the responses to each of the interview questions are characterized. A summary of the responses has been produced, which gives a comprehensive overview of the issue under study. Finally, a strategic framework for implementing change based on the findings is then proposed, involving several steps.

Question 1 asked how organizations approach change management in general. The first observation is that there are quite significant differences between companies in terms of their approach to implementing change, both on the basis of sector and size. Micro and small businesses take a more operational, unstructured approach to change management, and generally try to manage change on an ad-hoc basis. A very common shortcoming is that it is unsystematic. Medium-sized enterprises, on the other hand, point out that change management must be inextricably linked to project management, through which they try to implement major changes. There are also organizations that look for inspiration from existing models (the Kotter model was mentioned specifically), but add that implementing these models in full would be too resource intensive. A common element across all organizations is the emphasis on communication, which all businesses see as an essential element of successful change implementation.

The second question explored the biggest changes businesses have had to deal with in recent years. All enterprises report that clearly the biggest changes are technological innovations and changes related to the COVID-19 pandemic. However, technological innovations are not being implemented as expected, i.e. by implementing Industry 4.0. In fact, the most frequently implemented innovations are CRM or ERP systems, and within medium-sized enterprises, monitoring or artificial intelligence systems. At the same time, hybrid ways of working and accelerated digitization of processes have been implemented.

The following question then recorded what barriers enterprises register when implementing change. In all cases, the biggest barrier was the human factor. It is undeniable that the problems reported by enterprises are related to intergenerational differences. Older employees show their resistance to modern technologies and change in general, primarily because of concerns about their jobs or the complexity of adaptation. Very intensive communication was needed in all organizations and training was also frequent. A second significant barrier was the financial costs associated with change. Businesses also faced overload for some staff as the introduction of change ran in parallel with normal operations. An equally common barrier was the lack of experience with modern technologies and the incompatibility of the current technology base.

Businesses were then asked what technologies they were already using and how they specifically contribute to greater efficiency. Five types of innovation were commonly mentioned, namely CRM systems (most commonly HubSpot), automation of internal processes, use of Cloud, artificial intelligence and use of order management platforms with personalization. These technologies bring greater speed, accuracy and flexibility, improving not only companies' internal efficiency but also their customer relationships.

The next question asked how often companies implement changes or innovations. It was found that all businesses (regardless of industry), always implement change on an as-needed basis. However, in general, the frequency ranges from 6 months (IT) to 2-3 years (logistics, manufacturing). The primary reasons for their introduction are then customer requirements, competitive pressure, efficiency, and in the case of pharmaceuticals, adaptation to regulatory changes. Companies are aware that technological innovation is key to staying competitive and therefore digitalization is often part of their long-term strategies.

Question 6 was designed to find out how firms select the technologies they will introduce and whether they follow a predefined process. In most enterprises, the selection process is always systematic and involves a number of steps, with market research, pilot testing, employee involvement and determining return on investment identified as the main ones. Firms report that this process ensures that the technology not only meets the technical requirements but also supports the firm's strategic objectives.

Subsequently, firms were asked about the benefits that the innovations introduced bring to them. According to almost all respondents, the most important benefit is the increase in efficiency, as it is possible to handle a higher volume of work at the same or even lower cost. However, there are also a number of other benefits, with the most frequently cited by businesses being improved service to customers or clients and competitive advantage. Although technology adoption requires high investment and time, companies clearly see its benefits as key to their growth.

Question 8 was very important. This asked whether there were any technologies or changes that businesses were trying to implement but had so far been unsuccessful. In general, all categories of enterprises reported that such technologies and changes exist but always face the same obstacles. The most frequently mentioned then include more advanced automation, AI, integration of voice assistants and the use of IoT. In general, barriers are mainly related to funding, technical complexity and the need to align new technologies with existing systems.

Employees' perspectives on the introduction of innovation and change were then assessed by the next question. Employee reactions to new technologies vary by age, experience and role in the company. Younger employees and those with a technical background usually welcome innovation because it makes their jobs easier and improves performance. In contrast, older employees and those whose work is more routine may feel apprehensive about technological change. Businesses stress that the key to success is always communication, training and involvement in the change process itself. Companies recognize that the success of technology is largely dependent on employee acceptance.

Modern technology is also affecting the corporate culture to a large extent, which was characterized by the following question. Technology is changing corporate culture by increasing flexibility, transparency and collaboration between departments. For example, the introduction of cloud services has enabled real-time information sharing, which supports more effective communication and decision-making. Businesses then see the introduction of more flexible working patterns and changes in teamwork as other interventions in corporate culture. But in general, there is a trend towards a 'data culture' as companies increasingly rely on data analytics for decision-making, which is changing the way they define strategies and evaluate performance.

The current changes have also affected the customers of organizations. By implementing these changes, businesses have better insight into customer needs and can respond more quickly to customer demands. Specifically mentioned benefits include more transparent communication, personalization and faster service. Technology therefore not only increases efficiency, but also contributes to building trust and long-term relationships with customers.

In addition to the barriers, businesses have to overcome various challenges when introducing innovation. All companies mention that the introduction of new technologies often brings unexpected problems that prolong or complicate the implementation process. The most common challenges that required quick solutions included technical issues, time, logistical challenges and, of course, the human factor.

There were no clear conclusions in terms of funding. In general, enterprises use all basic sources of financing, i.e. own and external sources (loans) or subsidies. No strategic partnerships or alliances or investor input or joint-venture capital were identified. Firms recognize that effective planning and use of external resources is key to managing the costs of technological innovation.

In terms of future planning, firms then focus on efficiency, sustainability and competitiveness. They then cite expanding automation, adopting AI more widely, leveraging IoT and creating platforms for unified technology integration as key objectives. The execution of these plans is dependent on the availability of financial resources and the right partners, but companies see them as key to their future.

To conclude the interview, businesses were asked about how the changes and technologies introduced have impacted the way they communicate internally. Technology has fundamentally changed internal communication. Businesses now use modern platforms such as Microsoft Teams to enable efficient information sharing, rapid decision making and real-time collaboration. Key impacts include better collaboration, faster decision making or flexibility. However, companies stress that technology will not replace the need for face-to-face meetings, which are important for building relationships and trust.

The penultimate question was to assess the overall impact of technology on the business. Technology is considered a key factor for growth and competitiveness. The most frequently cited benefits are efficiency (in terms of the amount of work done relative to costs), increased quality and thus customer satisfaction, and the possibility of further innovation. Although the introduction of technology brings challenges such as high costs and the need for training, companies clearly perceive its impact as positive and necessary for future success.

Finally, firms were asked to evaluate the relationship between change management and the adoption of modern technology. Firms clearly perceive a strong relationship between change management and Industry 4.0 principles. Responses indicate that implementing technologies associated with Industry 4.0 (automation, data connectivity, artificial intelligence, IoT) requires structured change management, without which it would be difficult to integrate these advanced technologies into daily operations. One of the main findings is that change management is an essential skill for successful technology implementation, as without a carefully managed process, including impact analysis, planning and employee engagement, companies would not be able to leverage the full potential of Industry 4.0 technologies. A further link can be found in terms of transforming mindsets, where traditional approaches need to be rethought. Last but not least, businesses are seeing interdependencies. Management changes and Industry 4.0 technologies reinforce each other. Change management ensures that technologies are implemented correctly, and modern technologies in turn enable faster and more effective adaptation to change.

Companies conclude that Industry 4.0 is not only a technological revolution, but also a challenge to the way people, processes and corporate culture are managed. The emphasis on innovation and a structured approach to change management is therefore seen as a key element for success.

Based on the facts found throughout the research and taking into account the facts found in the qualitative part of the research, it is possible to construct the following diagram of the implementation of change and technological innovation in SMEs in the Czech Republic:

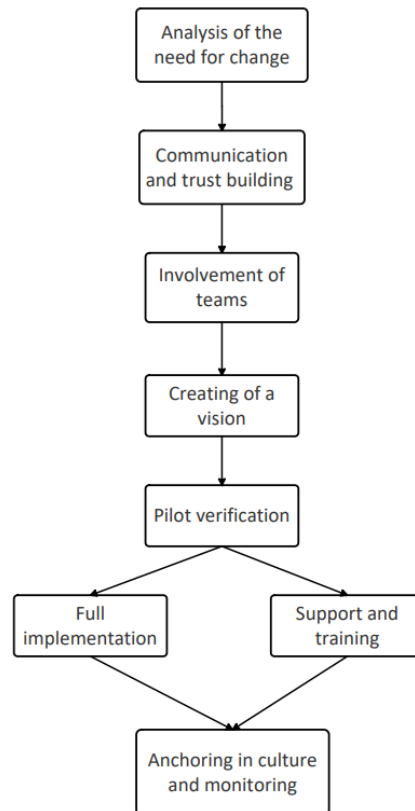


Figure 1. Change implementation strategic approach

The first step in implementing change should be to analyze the current situation and identify the reasons for change. These reasons are usually the unsustainability of the status quo (often cited as work in Excel) or pressure from the market or customers. The current processes and their shortcomings should be mapped and key staff should be involved at this step to make it clear what the change will mean for day-to-day practice. Process management is a very important discipline at this stage, as is project management, which can be used to implement change. It is equally important at this step to analyze possible sources of funding as a very significant barrier to implementing change.

The second step is communication and trust building. Businesses emphasize that explaining the benefits of change to employees and creating a sense of urgency has significantly reduced their resistance. It is important to introduce the change with an emphasis on benefits and to communicate the change through workshops and involve employees in the planning. It is also important to involve leaders who form work teams during the next steps and have a natural influence on the collective and support the change.

The third step should be to involve the teams. Businesses successfully involve employees in the planning process, which increases employee engagement and leads to the natural formation of leadership teams. It is highly desirable to use feedback from frontline employees. It is also appropriate to create working groups where employees can contribute their ideas. It is absolutely essential to listen to their concerns, which will be increasingly intense at this stage.

The fourth step is to create a vision. By the very fact that employees are involved in the planning, they are shaping the vision themselves. However, it is important to disseminate it to other employees. Strategic management and the alignment of the vision with the corporate strategy play an important role here, as does feedback on the vision from the organization's management. The vision of change must not be inconsistent with the personal aspirations of employees.

The fifth step is to pilot test the implementation of the change. The intensity of the pressure of employee resistance should decrease significantly at this stage or the resistance should have been completely overcome. Most companies reported that pilot testing was key to uncovering problems on a small scale. Pilot testing also helps to minimize resistance. For these reasons, it is desirable to implement the change first on a small, limited unit. It is still advisable to use feedback to optimize, and it is also imperative to have a response in place at this point to address potential technical issues such as incompatibility with current systems. Change needs to be introduced in small, non-violent steps that are easy to accept and it is important to give them enough time to get used to the new technology and processes.

After the pilot testing phase, full implementation occurs, but there must also be a support and training phase. Companies have noted that training not only on technical skills but also on reducing fear of the unknown has helped employees to embrace the changes. It is desirable to offer personalized training to meet the needs of different groups of employees. It is essential at this point to work with emotions and to acknowledge the fears of employees, as there is a renewed increase in the intensity of resistance since the old status quo is gone and the company has fully implemented the change.

The last step is then to anchor the change and monitor the processes. Organizations agree that change will only become sustainable in the long term if it is embedded in the corporate culture. Solutions are offered, e.g. by embedding them in the company's internal regulations. At the same time, the positive benefits of the change for the organization and the individual must be continuously highlighted. Even in the last step, it is necessary to create a space for reflection and feedback - regular workshops or informal meetings where changes are evaluated and further improved. Evaluating the benefits of change is absolutely essential, as is gathering feedback. All these aspects can help in future change implementation projects.

This framework builds on the experience of companies that have implemented various technological changes in recent years. Its key components are sequencing, an emphasis on communication and employee involvement, pilot testing and anchoring the changes in the company culture. In this way, even complex changes can be managed effectively in the context of Industry 4.0. In addition, it places significant emphasis on the human side of

implementing change. At the same time, it is important to note in conclusion that the role of change agent is held by the management, not by any of the employees.

4. Discussion

The fact that an analysis of the current state should come at the beginning of any change is not included in all change management models. In a way, this part is anchored, for example, in Kotter's model, where there should be an urgent need to trigger the desire for change (Kuffuor et al., 2024), or in the ADKAR model, where the initial phase should identify the necessary competences, knowledge and areas that will be affected by the change, all in line with the corporate strategy (Picado Argüello & González-Prida, 2024). The involvement of project management and the absolute necessity of careful planning is then mentioned by Errida and Lotfi (2021). In general, however, the models do not work very much in the first step with the necessity of an absolutely detailed process analysis already involving the rank and file.

In contrast, the second step, the need for high-quality two-way communication, is included in the vast majority of commonly used models. Blackman et al. (2022) point out that communication in the enterprise has many levels and all need to be given due attention as it is a necessary element of change. However, there are a number of studies that highlight the fact that lack of communication is a significant problem in implementing change or is a problem for other phases of the change process (Alshwayat et al., 2023; Karhapää et al., 2022). However, despite considerable awareness of this problem, there are still significant communication barriers to implementing change.

The need for teaming and creating a shared vision is an integral part of almost all models. The issue of teams and vision is very closely related to the previous part, which is communication. It is also in many cases linked to the area of leadership (Kaur Bagga et al., 2023; Higgs & Rowland, 2024). However, as reported by Czech SMEs, they do not expect one particular leader to perform, but rather to cluster them into groups, which then become teams to push for change. At the same time, the formation of teams and the subsequently shared vision are very closely linked (Groulx et al., 2023).

The pilot testing step is the fifth phase of the proposed procedure. Since it is considered in the above steps that the whole implementation is done through project management, pilot testing is almost an essential part. In general, it can be said that projects normally include pilot testing of project results or that entire pilot projects are directly involved in the implementation of innovations and changes (Boscherini et al., 2011; Füller et al., 2021).

The next phase of the actual implementation of the change is obvious. However, it comes with the need for continuous training and development of employees. As mentioned, a higher intensity of resistance can be expected in this phase, which can be addressed through workshops and training. The fact that training and skills development helps the acceptance of change is mentioned by Ferrari (2022). However, organizations must not neglect the education of their managers, who are considered change agents and, in the Czech context, leaders. The fact that leadership and manager education is also described by the literature (Henriksson & Grill, 2023).

The last phase is anchoring in the corporate culture and monitoring. The essential role of corporate culture in the implementation of change is emphasized by a number of models and is an integral part of the literature on the topic (Alshammari et al., 2024), with the topic of corporate culture very often being linked to the concept of leadership (Malik et al., 2024).

The limitations of this research stem from several aspects. It is necessary to take into account the sectoral and regional specificity of the sample, which was focused on the Czech business environment. Thus, the results may not be fully applicable in other countries or different economic conditions.

5. Conclusion

The main objective of this paper was to find a basic strategic framework according to which it would be possible to implement changes related to modern technologies in SMEs in the Czech Republic. This study highlights the key role of effective change management in the implementation of technological innovation in small and medium-sized enterprises (SMEs) in the Czech Republic. The interviews confirmed that approaches to change management vary significantly depending on company size. While micro and small enterprises tend to react to change in an ad-hoc and unstructured manner, medium-sized enterprises implement changes more systematically, often incorporating project management practices. The primary barriers perceived by businesses include employee resistance to new technologies, high costs, and technical challenges related to system compatibility.

Companies identified several critical success factors for implementing change. The first is a thorough analysis of the current state and the driving forces behind change, often initiated by external pressures such as customer demands or regulatory adjustments. Furthermore, effective communication and active employee involvement throughout the process were found to be crucial in overcoming resistance to change. Business experiences also confirm that pilot testing new technologies on a smaller scale significantly reduces risks and facilitates broader implementation. Additionally, ensuring the long-term sustainability of changes requires not only technical adaptation but also a shift in corporate culture and continuous evaluation of innovation benefits.

Based on these findings, a seven-phase strategic framework for change management was developed, reflecting real business experiences and providing concrete recommendations for successfully implementing technological innovations. This framework emphasizes the sequential nature of change implementation, its integration with project management, and, most importantly, the human factor as a key component of the process.

The results of this study confirm that successfully implementing change in SMEs within the context of Industry 4.0 requires not only technical expertise but also effective management of organizational and human aspects of change. The strategic framework developed through this research can help businesses overcome key barriers and enhance their competitiveness in a rapidly evolving digital environment.

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Conflict of interest: none

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The State of Crowdfunding Research: A Bibliometric Clustering Approach to Emerging Themes

Tomáš KRTIČKA* and Ivan SOUKAL

University of Hradec Králové, Hradec Králové, Czech Republic; tomas.krticka@uhk.cz; ivan.soukal@uhk.cz

* Corresponding author: tomas.krticka@uhk.cz

Abstract: Crowdfunding has emerged as a significant financing mechanism, allowing entrepreneurs, creators, and social initiatives to raise capital through online platforms. Despite its growing prominence, the academic literature on crowdfunding remains fragmented across multiple disciplines and perspectives. This study employs bibliometric analysis and clustering techniques to systematically categorize existing research on crowdfunding. By analyzing academic review articles published between 2019 and 2024 from Web of Science and Scopus databases, the study identifies five dominant thematic clusters: (1) Financial Technologies and Digital Transformation, (2) Entrepreneurial Finance & Innovation, (3) Medical and Social Crowdfunding, (4) Regulation and Risk Factors, and (5) Social Influence and Success Factors. Findings reveal gaps in literature, such as regulatory challenges, long-term sustainability of crowdfunding-backed ventures, and the role of trust in medical crowdfunding.

Keywords: crowdfunding; cluster analysis; financial technology

JEL Classification: M13; L26

1. Introduction

Crowdfunding has become an important way for entrepreneurs, creators, and social innovators to raise funds through collective contributions, primarily using online platforms. As crowdfunding continues to grow in popularity, it has attracted significant attention from researchers who aim to understand the motivations behind crowdfunding participation, the decision-making processes of backers, and the market dynamics that influence campaign success. This method of financing brings not only capital but also a closer connection between campaigners and contributors, which, however, increases demands on the creation of an effective ecosystem (Misciagna, 2024).

A close examination of previous studies shows that crowdfunding research covers a wide range of topics. Scholars have analyzed factors that determine campaign success, behavioral biases affecting backers' decision-making, the role of social networks, and the regulatory challenges of crowdfunding platforms. The diversity of disciplines, methods, and focal points in crowdfunding research raises important questions about how existing studies can be systematically organized and what insights can be gained from such an approach. There has been limited effort to systematically categorize and compare these studies. To address this gap, this review will apply bibliometric analysis and clustering

techniques to organize and synthesize existing research. By doing so, it will offer valuable insights for researchers looking to build on prior studies and identify key areas that require further investigation.

The goal of this study is to conduct a comprehensive review of the existing literature to determine whether crowdfunding research can be grouped into distinct thematic categories. Specifically, this study seeks to address the following key questions: (1) Can the current research be classified into clear thematic clusters? (2) What are the dominant themes within these clusters? (3) Do research gaps vary across these different themes? By answering these questions, this review aims to provide a clearer structure to the existing body of knowledge, helping identify areas that need further exploration and development.

This literature review will not only provide an overview of the current state of crowdfunding research but also highlight inconsistencies and underexplored areas that could inform future studies. Understanding how crowdfunding research is structured and where gaps exist will help scholars and practitioners develop more focused, interdisciplinary, and impactful research strategies.

2. Methodology

To address the first two research questions – (1) Can the current research be classified into clear thematic clusters? and (2) What are the dominant themes within these clusters? A cluster analysis of academic review articles on crowdfunding was conducted. The dataset consists of articles published between 2019 and 2024, retrieved from Web of Science and Scopus databases using the search term "crowdfunding." The analysis was performed using VOSviewer, a bibliometric mapping tool, which is using an optimization algorithm that assigns nodes to groups of closely related items thus creating keyword maps, based on co-occurrence data, which employ clustering to reveal thematic structures within a dataset. For visualization, color-coding differentiates clusters, helping in the interpretation of relational patterns.

For research question 3, *"Do research gaps vary across these different themes?"* A systematic literature review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a transparent and replicable research process. This approach provided a structured method for identifying, screening, and analyzing relevant studies. The literature search was carried out in two major academic databases, Web of Science and Scopus, both of which are widely recognized for their extensive collection of peer-reviewed research.

To refine the search, specific inclusion criteria were applied. The keyword "crowdfunding" was used as the primary search term to identify relevant studies. Only review articles were considered to ensure the analysis focused on synthesized findings rather than individual empirical studies. Additionally, the publication date range was restricted to 2019–2024 to include the most recent and relevant literature. To assess the academic impact of the selected articles, only those with at least 10 citations were included in the final selection. Articles with fewer than 10 citations were excluded, as they were considered to have limited influence within the research community.

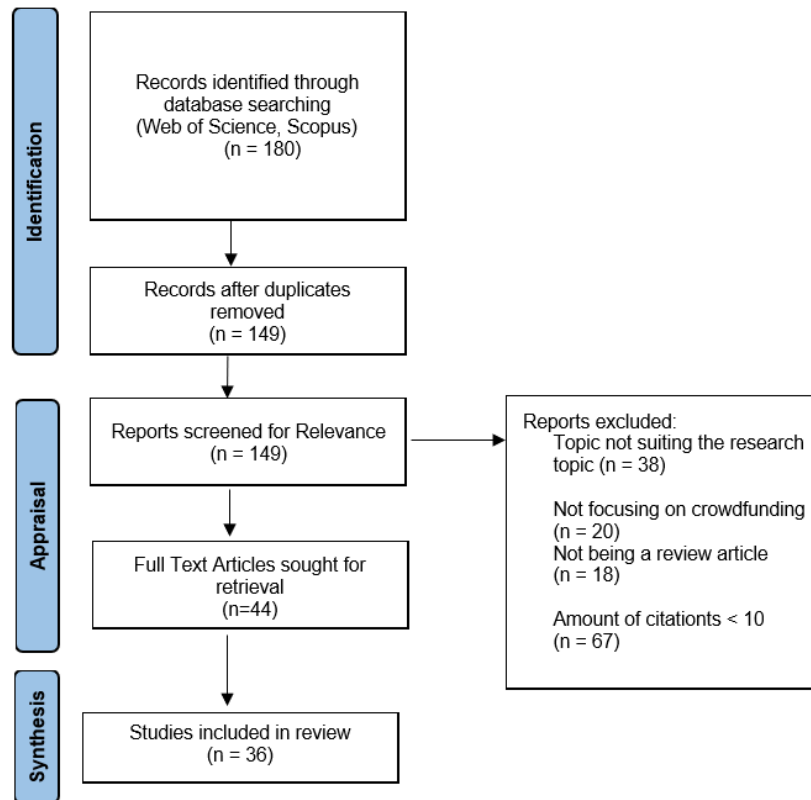


Figure 1. Publication search process according to PRISMA

- Identification – Initial retrieval of 180 articles from Web of Science and Scopus.
- Screening – Removal of duplicates, leaving 149 articles for review.
- Eligibility – Articles were assessed for relevance and academic impact:
 - 20 articles were excluded for not focusing on crowdfunding, 18 articles were excluded because those articles were not review articles.
 - 67 articles were excluded due to having too few citations, indicating limited academic impact.

3. Results

3.1. Research Question 1: Can Articles Be Clustered by Topics?

This study aimed to determine whether research articles on crowdfunding could be categorized into thematic clusters based on their content. To achieve this, clustering was performed using VOSviewer, a tool designed for bibliometric analysis and visualization.

The clustering process involved analyzing the abstracts of research articles to identify keywords and thematic patterns. Articles were sourced separately from Scopus and Web of Science. Using VOSviewer, keyword co-occurrence networks were created for each dataset, enabling the identification of distinct subtopics within the field of crowdfunding.

Cluster analysis of articles from Scopus database presents a visual representation of key themes in crowdfunding research. The analysis identifies five distinct clusters, each representing a different aspect of crowdfunding, including its core concepts, technological influences, financial applications, success factors, and niche areas.

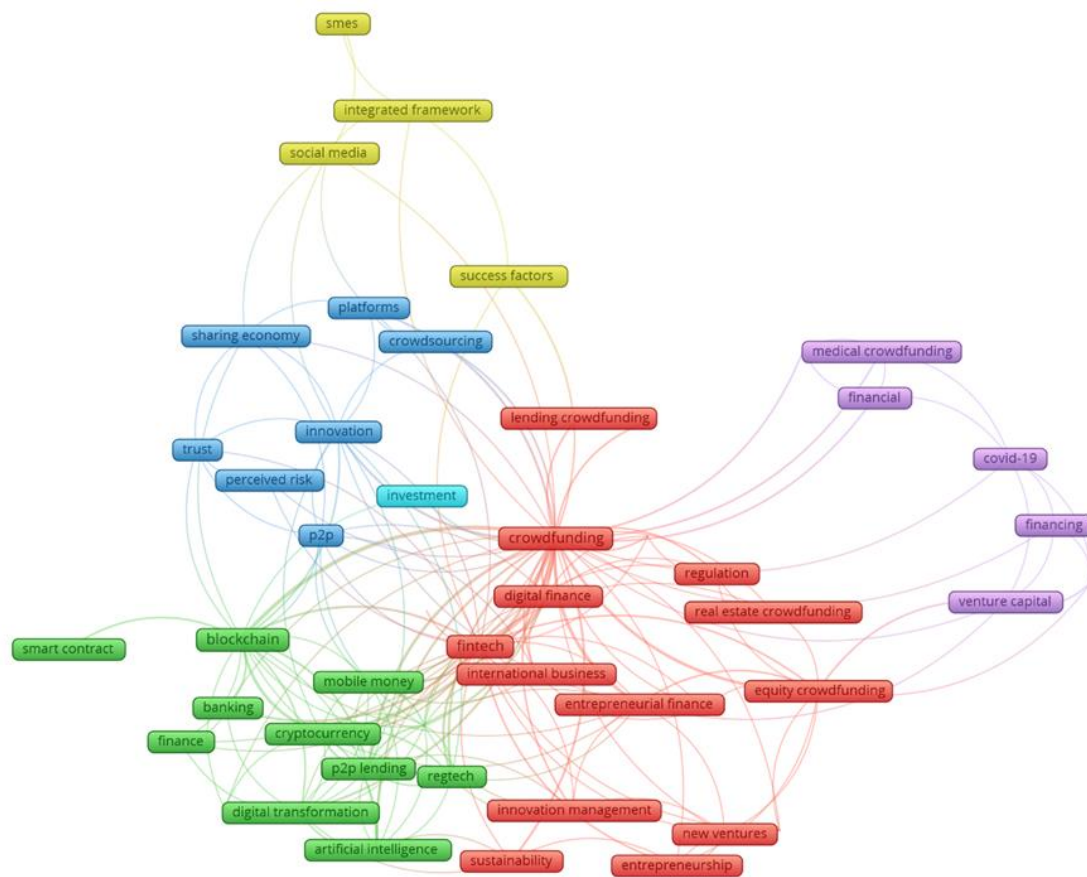


Figure 2. Keyword analysis of articles in Scopus database.

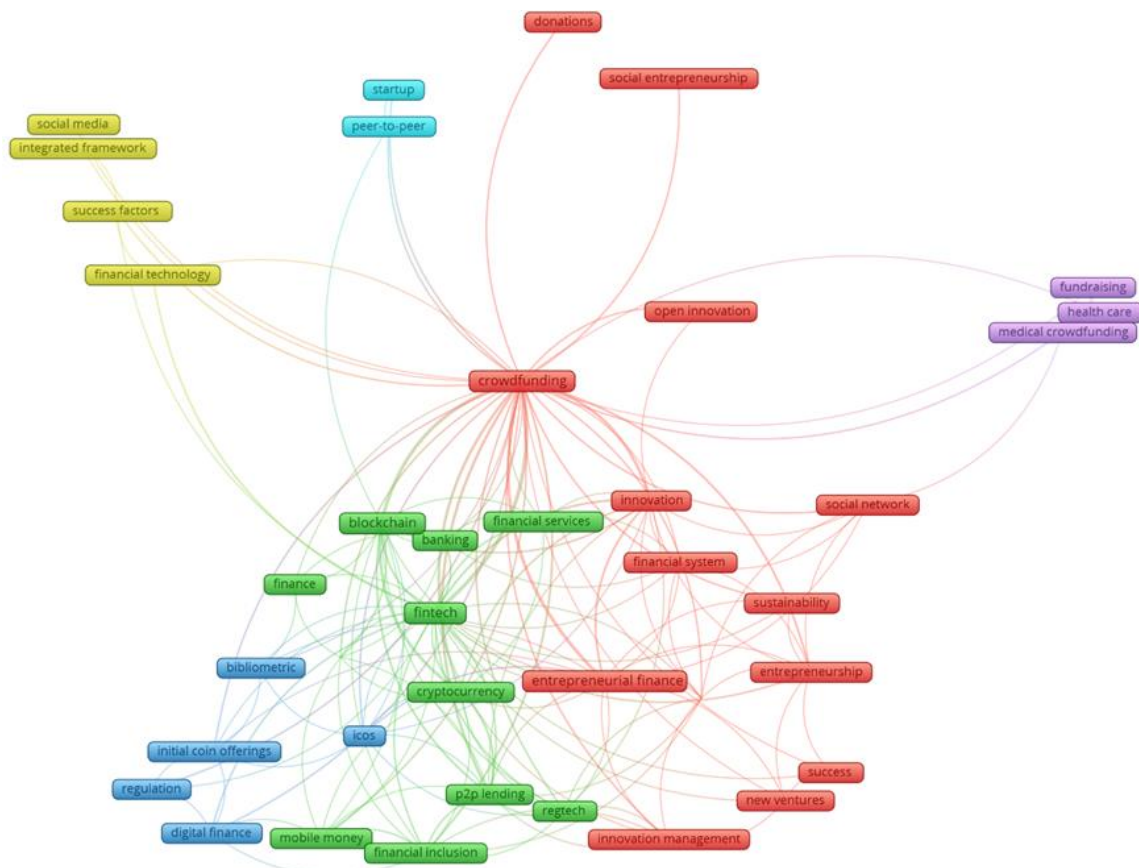


Figure 3. Keyword analysis of articles in Web of Science articles

The cluster analysis of crowdfunding research from Web of Science identifies again five main thematic clusters, each representing different dimensions of the field.

Both maps reveal distinct yet overlapping research themes, highlighting the dominant topics and their interconnections within the academic discourse on crowdfunding. This combined analysis confirms that crowdfunding research can be clustered into clear thematic groups.

3.2. Research Question 2: What Are the Dominant Themes within Identified Clusters?

Both keyword maps indicate that crowdfunding serves as the central research focus, connecting various subtopics. The analysis identified five primary clusters:

1. Financial Technologies and Digital Transformation,
2. Entrepreneurial Finance & Innovation,
3. Medical and Social Crowdfunding,
4. Regulation and Risk Factors.
5. Social Influence and Success Factors in Crowdfunding.

Each cluster highlights a distinct aspect of crowdfunding research, reflecting its broad and interdisciplinary scope. This categorization emphasizes the complexity of crowdfunding as a multifaceted phenomenon with significant implications across various fields, including healthcare fundraising, financial technology, and regulatory frameworks. Some of the most prominent recurring themes include:

1. Entrepreneurial Finance & Innovation (red clusters):

These clusters, covering topics such as entrepreneurship, innovation management, success factors, and new ventures, emphasize research on crowdfunding's role in supporting startups and business development.

2. Financial Technologies and Digital Transformation (green clusters):

Both maps identify blockchain, cryptocurrency, fintech, and P2P lending as important themes, reflecting the growing role of digital finance in crowdfunding.

3. Medical and Social Crowdfunding (purple clusters):

Keywords such as medical crowdfunding, healthcare, and fundraising indicate a research focus on crowdfunding's social and philanthropic dimensions, especially concerning healthcare and charitable donations.

4. Regulation and Risk Factors (blue clusters):

Both maps include terms like regulation, perceived risk, and trust, indicating that governance and investor confidence remain critical areas of interest.

5. Social Influence and Success Factors in Crowdfunding (yellow cluster):

Yellow cluster appears in both maps, encompassing terms like social media, success factors, SMEs (small and medium enterprises), integrated framework, and financial technology. This cluster highlights the role of social influence, digital engagement, and strategic factors in crowdfunding success.

Table 1. Reviewed articles by topic

Article	Topic				
	Financial Technologies and Digital Transformation	Entrepreneurial Finance & Innovation	Medical and Social Crowdfunding	Regulation and Risk Factors	Social Influence and Success Factors in Crowdfunding
Alhammad et al., 2021				x	
Ali et al., 2022					x
Bargoni et al., 2022					x
Bhatt et al. 2022	x				
Bollaert et al., 2021	x				
Cai et al., 2020		x			
Chaudhary et al., 2022		x			
Coakley & Lazos, 2021		x			
Cumming et al., 2023	x				
Deng et al., 2022		x			
Dinh et al., 2024		x			
Gupta et al., 2024				x	
Guy, 2022				x	
Hou et al., 2022			x		
Hua et al., 2019	x				
Jeliničić & Šveb, 2021		x			
Lăzăroiu et al. 2023	x				
Li et al., 2020	x				
Mazzocchi & Lucarelli, 2022					x
Miglo, 2022		x			
Milian et al. 2019	x				
Mora-Cruz & Palos-Sanchez, 2023		x			
Olanrewaju et al., 2019					x
Pandey et al., 2023	x				
Parrick & Chapman, 2020			x		
Popescu et al., 2020		x			
Rabbani et al., 2022		x			
Sharma et al., 2023	x				
Shneor & Vik, 2020					x
Sun et al., 2022	x				
Takeda & Ito, 2021	x				
Talukder & Lakner, 2023		x			
Van Teunenbroek et al., 2023		x			
Wehnert & Beckmann, 2021					x
Yasar, 2021				x	
Yu & Fleming, 2021					x

3.3. Research Question 3: Do Research Gaps Vary Across these Different Themes?

Financial Technologies and Digital Transformation (n = 11)

Key themes of those articles include the role of digitalization in financial services, the integration of blockchain technology, and the rise of fintech startups. A common research gap across these studies is the insufficient exploration of regional differences, especially how cultural and socio-economic factors affect crowdfunding success and fintech adoption. Many studies also focus on public data, lacking deeper insights into funder behavior or the subjective evaluation of crowdfunding campaigns. Another gap is the limited understanding of regulatory impacts, particularly how different regulatory frameworks shape fintech innovation and the adoption of digital financial services. There is also a need for more longitudinal studies that track fintech and crowdfunding trends over time. Lastly, the integration of emerging technologies like AI, big data, and blockchain in fintech remains underexplored, presenting opportunities for future research.

Entrepreneurial Finance & Innovation (n = 12)

Research on crowdfunding success factors reveals several important gaps. A significant area of concern is the lack of understanding regarding the long-term performance of crowdfunding ventures. Most studies focus on short term funding success, but little is known about the financial stability, growth trajectory, and survival rates of these ventures compared to those funded through traditional methods. The lack of research prevents complete analysis of how crowdfunding affects entrepreneurial success over time. Furthermore, while crowdfunding has been recognized for democratizing entrepreneurial finance, there is little research comparing its success rates and venture outcomes to traditional financing methods. This makes it difficult to determine the broader implications of crowdfunding on entrepreneurship. Research on the interaction between crowdfunding and different regulatory environments is another underexplored area, as it could have a significant impact on both the efficiency and sustainability of crowdfunding platforms.

Medical Crowdfunding (n = 2)

The existing literature on medical crowdfunding explores factors influencing donation behavior, campaign success, and ethical concerns. One notable gap concerns the discrepancy between stated donor preferences and actual donation behavior. While surveys suggest a preference for funding campaigns related to common or severe illnesses, real-world data indicate that rare disease campaigns perform equally well.

Another underexplored area is the role of trust and concerns about fraud. While transparency is considered key, few studies examine how fears of misuse or fraud affect donors' willingness to contribute. Additionally, the long-term impact of medical crowdfunding remains insufficiently studied. Most research focuses on the immediate success of campaigns, leaving open questions about how repeated crowdfunding efforts influence donor engagement, potential fatigue, and trust in the system over time.

Regulatory and Legal Considerations (n = 4)

Research on regulatory frameworks in crowdfunding reveals their influence on financial and legal risks of crowdfunding while describing gaps in governance. A major issue is the lack of universal regulatory structures, which exacerbates risks for users. While studies highlight inconsistencies in legal crowdfunding. It is addressed how adaptive legal frameworks could enhance compliance and accessibility.

Another area requiring further exploration is the potential of blockchain-based transparency to reduce financial and legal risks. While transparency is critical in crowdfunding, few studies investigate how decentralized verification mechanisms could protect investors.

Social Influence and Success Factors in Crowdfunding (n = 7)

Research on entrepreneurial social influence and success factors in crowdfunding describes how social capital, networks, and trust shape funding in this sector. Most described gap is the limited understanding of how is backer behavior influenced by algorithm driven recommendations. Another underexplored area is the impact of cultural and regional differences. Most research is focused on western crowdfunding platforms, meaning they don't mention how social influence dynamics may vary across different cultures. Lastly, while short term funding success is widely studied, the long-term effects of social capital on business sustainability and investor retention isn't examined enough.

4. Conclusions

This study aimed to provide a structured overview of the academic research on crowdfunding by identifying thematic clusters and analyzing key trends within the field. Using bibliometric analysis and systematic literature review methods, the study categorized existing research into five main themes: Financial Technologies and Digital Transformation, Entrepreneurial Finance & Innovation, Medical and Social Crowdfunding, Regulation and Risk Factors, and Social Influence and Success Factors. These clusters illustrate the interdisciplinary nature of crowdfunding research, covering aspects of finance, technology, entrepreneurship, and social behavior.

The findings reveal that while crowdfunding has received increasing academic attention, several research gaps remain. One major gap is the lack of standardized regulatory frameworks, which affects investor protection and platform governance. Similarly, while much research has explored the determinants of crowdfunding success, fewer studies have examined the long-term sustainability of crowdfunded ventures and how these projects perform after receiving initial funding. In medical crowdfunding, issues related to trust, transparency, and donor behavior remain underexplored, particularly regarding the impact of fraud concerns on funding decisions. Furthermore, the influence of social capital and digital engagement strategies in crowdfunding success requires deeper investigation, especially in different cultural and regional contexts.

By organizing existing research into thematic clusters, this study contributes to a clearer understanding of the current state of crowdfunding literature. It also provides a foundation for future research by highlighting areas that require further exploration.

Conflict of interest: none

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The Impact of Global Trade and Globalization on the Hotel Services Market in Czech and Slovak Republic

Renáta KŘEČKOVÁ, Daniela ŠÁLKOVÁ* and Sergei YEKIMOV

Czech University of Life Sciences Prague, Prague, Czech Republic; kreckovar@pef.czu.cz; salkova@pef.czu.cz; yekimov@pef.czu.cz

* Corresponding author: salkova@pef.czu.cz

Abstract: Global trade and globalisation have significantly affected the hotel services market, especially in the Czech and Slovak Republics. These changes affect supply and demand dynamics, leading to market homogenisation or differentiation based on cost-effectiveness and sustainability. This study examines the key factors influencing hotel prices and expenditure between 2007 and 2023, focusing on the role of energy costs and employee remuneration in shaping turnover. Using economic modelling and statistical analysis, the research identifies a strong relationship between these costs and hotel sales, with inflation negatively impacting demand. The study confirms that rising energy costs and wages contribute to fluctuations in accommodation prices, which affects the competitiveness of the tourism industry. Moreover, inflation exhibits a time lagged elastic effect, further complicating financial stability in the sector. The findings provide valuable insights for policy makers and industry stakeholders and highlight the need for strategic cost management and sustainable development to remain competitive in a globalised hospitality market.

Keywords: global trade; globalization; accommodation services; electricity price; wage

JEL Classification: M31; L21; L26

1. Introduction

The hospitality industry operates in a globalised framework that is significantly influenced by the dynamics of international trade. This global context has led to the adoption of innovative strategies and the restructuring of business models in order to remain competitive (Pugachov, 2022). The industry has seen a shift towards digital transformation, sustainability and service diversification to meet the evolving demands of a segmented market (George, 2021). These changes are driven by globalisation, which requires the internationalisation of operations and the adoption of sophisticated financial mechanisms to support expansion (Costa & Costa, 2022). The hospitality industry is increasingly embracing technological innovations that improve customer experience and operational efficiency. This includes the use of digital platforms for reservations and customer interaction, as well as the introduction of artificial intelligence and machine learning into operations (Marques & Marques, 2023) (El Archi & Benbba, 2024). Globalization has led to the internationalization of hotel chains, which use various entry modes to penetrate new markets (Moskalenko et al., 2021). The global hospitality market

is characterised by intense competition, with new regional markets emerging in Asia Pacific and the Middle East. However, these regions are facing challenges such as increased travel costs and regulatory restrictions (Pavliuk, 2022). Globalisation presents opportunities for growth and innovation but also challenges such as increased competition and the need to constantly adapt to changing consumer preferences. The hospitality industry must manage these dynamics by harnessing technology, exploring new markets and maintaining a focus on sustainability to thrive in a globalised economy (Kvach et al., 2018).

Key performance indicators (KPIs) such as average daily rate (ADR) and revenue per available room (RevPAR) are traditional metrics used to measure the success of the travel and hospitality industry. However, these indicators may not fully capture the broader economic impacts of tourism, such as tourist spending on various services (Vogel, 2016). A more comprehensive measure, such as spend per day across all services, can provide a better understanding of the economic contribution of tourism (Purwono et al., 2024). This approach takes into account wider economic impacts, including job creation, contribution to GDP and interdependence with other sectors (Voukkali et al., 2023). Tourism expenditure has a significant impact on the performance of the economy, as demonstrated by its relationship with GDP and employment in the euro area (Pardinha et al., 2023). The bidirectional relationship between tourism expenditure and economic performance highlights the role of this sector in economic growth and job creation (Anagnostou et al., 2021). Supply-side factors such as energy costs and staff remuneration play a crucial role in determining hotel prices and, consequently, influence overall tourist spending (Philander & Roe, 2013).

Labour costs have been identified as a significant determinant of tourism expenditure, with a negative relationship between rising labour costs and tourism competitiveness (Chen et al., 2021). This relationship is mainly due to the impact of labour costs on the supply side of tourism, where increased costs can lead to higher prices for tourism services, thereby reducing demand and competitiveness (Li et al., 2018). Energy costs are a critical factor influencing the economic health of hospitality businesses, affecting both pricing strategies and profitability (Xu & Liu, 2023). The hospitality industry, particularly hotels, is energy-intensive due to the need to provide continuous services such as heating, cooling, and lighting (Rajić et al., 2022).

2. Methodology

Paper aims to explore the effect of the energy costs set internationally at EEX and wages impacted globally on accommodation prices of hotels and similar accommodations in Czech Republic and Slovak Republic between 2007 and 2023. Since the initial values in our study are tabular values, from a mathematical point of view, we reduce the solution to differentiating a function given in the form of a table by constructing Dirichlet series. Our analysis includes a dataset covering the Czech Republic and Slovakia between 2007 and 2023 due to availability of data. Using the model, we have tried to assess the impact of energy costs and employee remuneration on accommodation establishments' turnover

represented by index of accommodation services in Czech Republic and Slovakia. Due to economic instability, wage and asset-based incomes are prone to fluctuations, which in turn effect on price level of hotels and similar accommodation establishments measured by Average daily rate (ADR). As a result of restricted availability and accuracy of price related data represented by ADR cojoined with trade secret and limited willingness to disclose relevant information per country, the index of hotels and similar accommodation establishments and restaurants were used. Data were collected from different sources, i.e., Czech Statistical Office, Eurostat, World Travel, Tourism Council and Tourism Economic Impact annual reports and data provided by The World Bank database. Due to the limited availability and accessibility of data, this study refers to the timeframe spanning from 2000/2007 to 2023 using Turnover index in accommodation services in Czech Republic and Slovak Republic - monthly unadjusted data. Average wages in accommodation and restaurant as well as Average wages in economy of Czech Republic and Slovak Republic and Energy costs of non-household were considered as explanatory factors. Energy costs specifically are simplified and funnelled to electricity costs collected with half year periodicity from 2007 and categorised as per average consumption. Typical hotel and similar accommodation's electricity consumption is falling to the category of yearly consumption between 20 MWh to 1,999 MWh, whereby overall electricity consumption depends on the average occupancy of the establishment and offered services. Each data set refers to the quarter periodicity. Analysed was relationship between the Prices measured by Turnover index, in hotels and similar accommodations, and variables impacting costs including the Average wages and Energy costs of non-households in each respective country, specifically in the Czech Republic and Slovakia.

The model is set to study hypothesis:

- Hypothesis 1 (H1): There is a negative association between energy costs and remuneration packages of tourism employees and accommodation establishments' turnover. The higher disponible income in tourism industry has negative influence on accommodation establishments' turnover and tourists spent.
- Hypothesis 2 (H2): There is a negative association between the accommodation establishments' turnover and inflation ratio. Higher inflation in destination negatively influences tourism demand at all, including residents and turnover of accommodation establishment.

To evaluate the development of prices of hotels and similar accommodations we used following approach. The coefficient of elasticity occupies an important place in economic calculations. It shows how much the value of one attribute changes, provided that the other attribute changes relatively.

$$\varepsilon = \frac{dy}{dx} \cdot \frac{x}{y} = \frac{\frac{dy}{dt}}{\frac{dx}{dt}} \cdot \frac{x}{y} \quad (1)$$

For example, elasticity coefficients are included in the model's Autoregressive model (AR), Autoregressive Distributed Lags model (ADL), Vector Autoregression model

(VAR). Autoregressive model (AR) describes the behaviour of time series in which the current values have a linear dependence on the previous values for each series, respectively:

$$X_t = c + \sum_{i=1}^p a_i X_{t-i} + \varepsilon_i \quad (2)$$

where $c = \text{const}$, a_1, a_2, \dots, a_p – regression coefficients, and ε_i is white noise.

Autoregressive Distributed Lags model (ADL) describes the behaviour of time series whose values depend not only on the past values of these time series, but also on the values of other time series:

$$y_t = a_0 + \sum_{i=1}^p a_i y_{t-i} + \sum_{j=0}^q b_j x_{t-j} + \varepsilon_i \quad (3)$$

where a_0, a_1, \dots, a_p and b_0, b_1, \dots, b_p are regression coefficients, and ε_i is white noise.

Vector Autoregression model (VAR) it also describes the behaviour of time series whose values depend not only on the past values of these time series, but also on the values of other time series:

$$y_t^i = a_0^i + \sum_{j=1}^k a_{1j}^j y_{t-1}^j + \sum_{j=1}^k a_{2j}^j y_{t-2}^j + \dots + \sum_{j=1}^k a_{pj}^j y_{t-p}^j + \varepsilon_t^i \quad (4)$$

where $a_0^i, a_{1j}^j, a_{2j}^j, \dots, a_{pj}^j$ are regression coefficients, and ε_t^i is white noise.

Table 1. Accepted designations for variables used in the analysis

Autoregressive model (AR)	$a_i = \frac{dX_t}{dX_{t-i}}$
Autoregressive Distributed Lags model (ADL)	$a_i = \frac{dy_t}{dy_{t-i}}, b_j = \frac{dy_t}{dx_{t-j}}$
Vector Autoregression model (VAR)	$a_i^j = \frac{dy_{t-i}^j}{dy_t^i}$

3. Results

To assess the price trends of hotels and similar accommodations, we employed the method of elasticity coefficient to set the extent to which one accepted designation mentioned in Table 2. responds to each other changes. Results are visible in Figure 1. and Figure 2.

Table 2. Accepted designations

Electricity prices 2007–2023 – non-household large hotels CZ	CZ_EP_HOT
Electricity prices 2007–2023 – non-household large hotels SK	SK_EP_HOT
Electricity prices 2007–2023 – non-household CZ	CZ_EP_NON
Electricity prices 2007–2023 – non-household SK	SK_EP_NON
Index services - revenue – Accommodation + Restaurants CZ	CZ_IS
Index services - revenue – Accommodation + Restaurants SK	SK_IS
Accommodation + Restaurants services CZK – average income in CZ	CZ_MZDA
Total average income SK	SK_MZDA
HICP - inflation- rate of change CZ	CZ_HICP
HICP - inflation- rate of change SK	SK_HICP
The time derivative of Electricity prices 2007–2023 – non-household large hotels CZ	$d(CZ_EP_HOT)/dt$
The time derivative of Electricity prices 2007–2023 – non-household large hotels SK	$d(SK_EP_HOT)/dt$
The time derivative of Electricity prices 2007–2023 – non-household CZ	$d(CZ_EP_NON)/dt$
The time derivative of Electricity prices 2007–2023 – non-household SK	$d(SK_EP_NON)/dt$
The time derivative of Index services - revenue – Accommodation + Restaurants CZ	$d(CZ_IS)/dt$
The time derivative of Index services - revenue – Accommodation + Restaurants SK	$d(SK_IS)/dt$
The time derivative of Accommodation + Restaurants services CZK – average income in CZ	$d(CZ_MZDA)/dt$
The time derivative of Total average income SK	$d(SK_MZDA)/dt$
Coefficient of elasticity CZ_HICP in relation to CZ_EP_HOT	CZHICP/CZEPOT
Coefficient of elasticity CZ_HICP in relation to CZ_EP_NON	CZHICP/CZEPNON
Coefficient of elasticity CZ_HICP in relation to CZ_IS	CZHICP/CZIS
Coefficient of elasticity CZ_HICP in relation to CZ_MZDA	CZHICP/CZMZDA
HICP - inflation- rate of change CZ	CZHICP
Coefficient of elasticity SK_HICP in relation to SK_EP_HOT	SKHICP/SKEPOT
Coefficient of elasticity SK_HICP in relation to SK_EP_NON	SKHICP/SKEPNON
Coefficient of elasticity SK_HICP in relation to SK_IS	SKHICP/SKIS
Coefficient of elasticity SK_HICP in relation to SK_MZDA	SKHICP/SKMZDA
HICP - inflation- rate of change SK	SKHICP

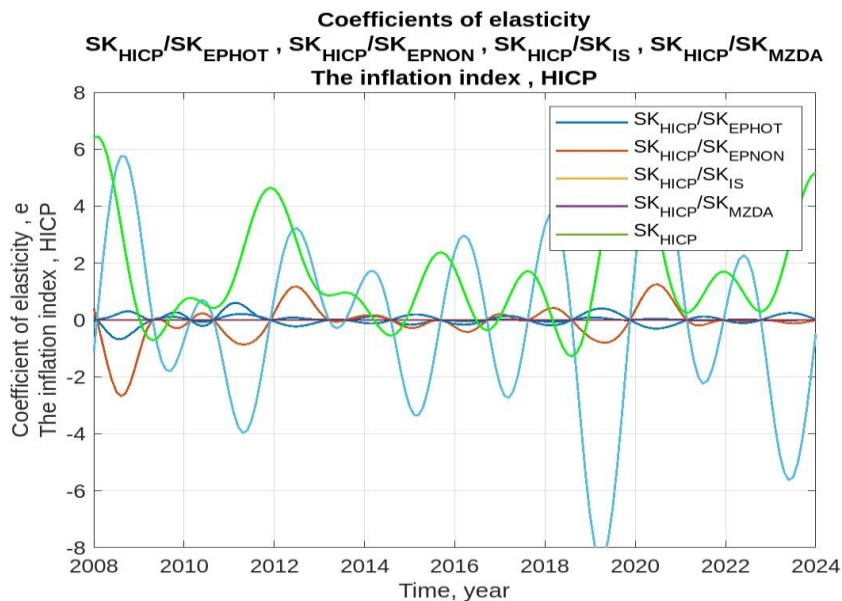


Figure 1. Coefficients of elasticity SKHICP/SKEPHOT, SKHICP/SKEPNON, SKHICP/SKIS, SKHICP/SKMZDA

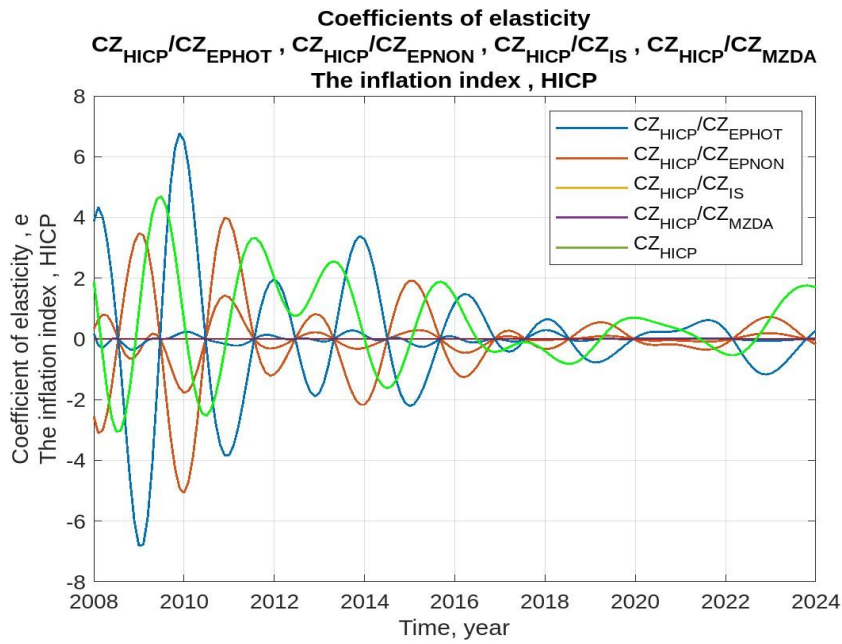


Figure 2. Coefficients of elasticity CZ_{HICP}/CZ_{EPHOT} , CZ_{HICP}/CZ_{EPNON} , CZ_{HICP}/CZ_{IS} , CZ_{HICP}/CZ_{MZDA} , CZ_{HICP}

Results for studied Hypothesis 1 (H1) are shown in the Figure 3. of the elasticity of inflation in relation to wages and the Figure 4. of the elasticity of inflation in relation to electricity prices are periodic. The hypothesis is confirmed, but not in all years. The hypothesis is confirmed when the Figure of the elasticity of inflation in relation to wages and the Figure of the elasticity of inflation in relation to electricity prices have a different orientation and is not confirmed when the Figure of the elasticity of inflation in relation to wages and the Figure of the elasticity of inflation in relation to electricity prices have a different orientation.

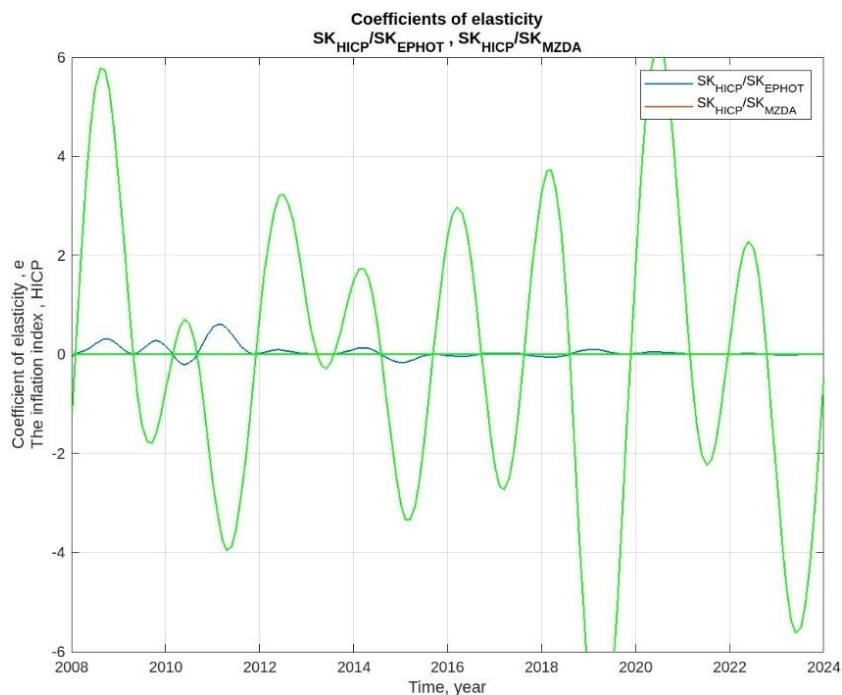


Figure 3. The elasticity of inflation in relation to wages - SK

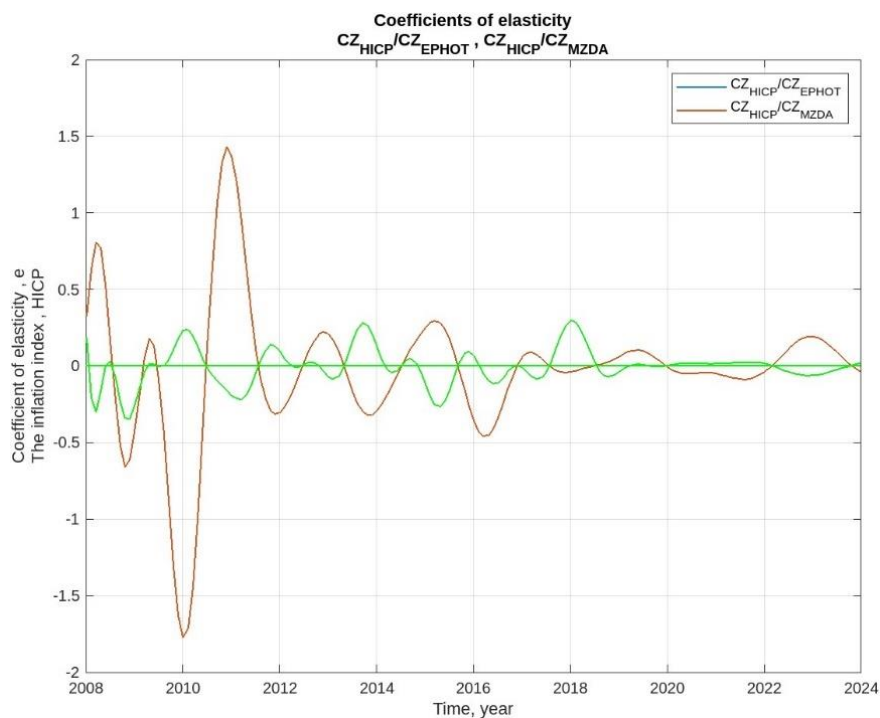


Figure 4. The elasticity of inflation in relation to electricity prices - CZ

Hypothesis 2 (H2) set: There is a negative association between the accommodation establishments' turnover and inflation ratio. Higher inflation in destination negatively influences tourism demand at all, including residents and turnover of accommodation establishment, is confirmed, however, there is a time lag between the maxima of the coefficient of elasticity of inflation according to the index of services and the index of inflation, shown in Figure 5. and Figure 6.

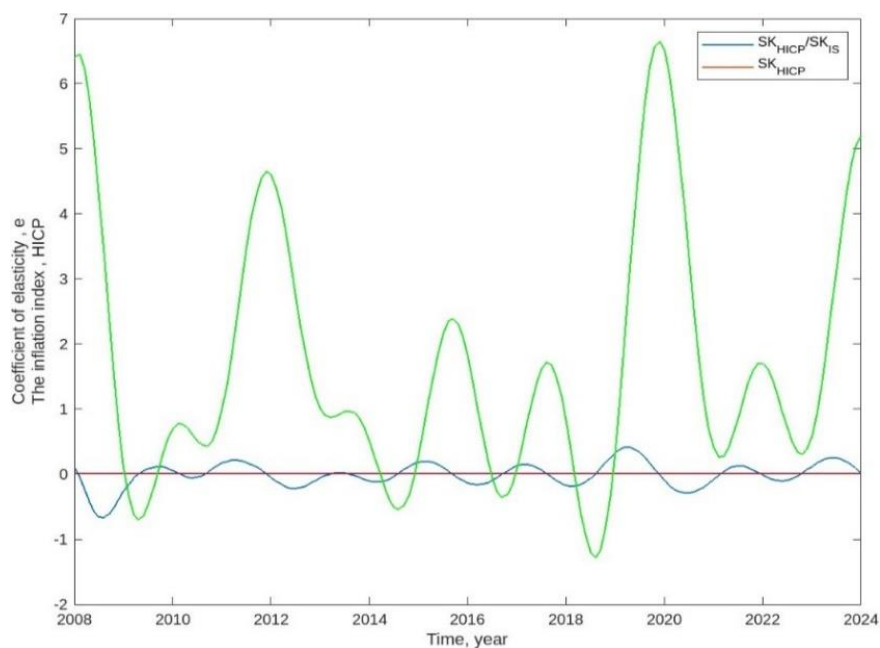


Figure 5. The elasticity of inflation index HICP - SK

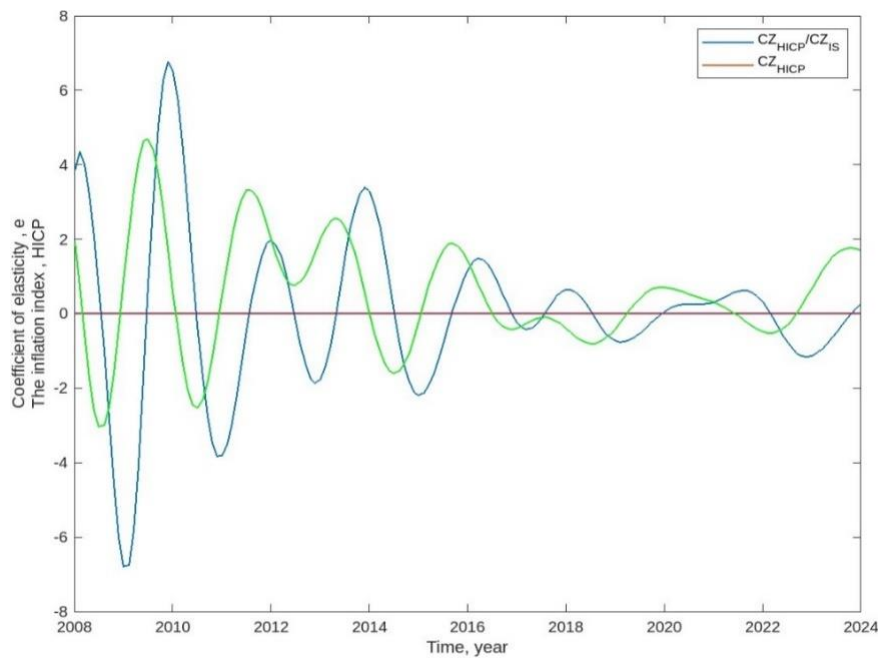


Figure 6. The elasticity of inflation index HICP - CZ

4. Discussion

Study directed the attention to the investigation of the effect of the energy costs reduced to volatile electricity prices set internationally at EEX and wages impacted globally on accommodation prices of hotels and similar accommodations in Czech Republic and Slovak Republic between 2007 and 2023. Current research is directed to wider area and employs econometric models to explore causal relationships, frequently using the number of arriving tourists or overnight stays as dependent variables. Independent variables typically include GDP per capita, inflation rate, and exchange rate. Alternatively, empirical and descriptive methods with panel data are also utilized. The results suggest that market factors are the primary influencers of global strategy, while other drivers play a significantly lesser role. Cost drivers are limited by the narrow scope for economies of scale and standardization opportunities. Globalization is most evident in the push for a wide geoFigureic presence in crucial international markets, the quest for global branding, and the establishment of consistent service standards (Whitla et al., 2007). Current literature is evidence of investigation in the field of internationalisation and globalisation in hotel industry. Particularly studies have been investigating several points of view, from development of global strategies (Hall, 1997) to investigating the critical issues of globalisation itself (Yu et al., 2014) and taking specific economic-geoFigureical approach (Niewiadomski, 2014). Globalisation is phenomenon influencing the activities in trade worldwide, however our interest is more directed to central Europe (Niewiadomski, 2016). The results of these studies are focusing on maintaining harmonized global presence with no impact on local community avoiding negative impact as mass tourism, implementing integration of international value-added activities in areas such as human resources and purchasing with focus on cost effectivity. UNWTO report has been dedicated to overtourism and includes 18 studies how to manage and mitigate the negative impact of overtourism. Specifically observed field is

human recourses and remuneration of employees. The study of Al Hrou and Mohamed (2014) enhanced the understanding of practical issues of Human resource management more importantly since it involve organizing the management of human resources, with respect to accomplishment of organizational objective furthermore it shows that the issues either related to external factors, which include technological change, legislation and regulation, and national culture, globalization, or internal factors including size, industry and sector characteristic and structure of an organization, strategy and past practice of human recourses including management of remuneration packages (Al Hrou & Mohamed, 2014). Impact of tourism on employment was described as econometric model which showed the positive impact of tourism on employment in the economy of Central and Eastern European Countries (CEE) at regional level. The study focused in those eight countries from Central and Baltic Europe that became members of the European Union in year 2004 (Aguayo, 2011). Electricity prices were considered as one of variable factors in article of evaluating the pandemic's impact on the dynamics and structure of household expenditures in Central and Eastern Europe. The research was based on statistical data analysis and trend analysis in period of 2017 - 2021. Results confirmed that less income received due to the COVID-19 pandemic effect, significantly reduced their expenditures, and preferred savings over investment (Vilchynska et al., 2023). Flexible energy demand is seen as one solution to integrate intermittent renewable energy sources into future energy systems as a response of volatile electricity costs. A comprehensive analysis of the demand potential of the service sector, using a transparent bottom-up approach, along with quantitative survey data from a large sample size of over 1500 German companies was provided with results that relevant barriers to demand response are its perceived low priority and inadequate financial incentives due to a small share of energy costs within firms, whereas customer image of demand response is perceived as an important driver (Wohlfarth et al., 2020). Compared to residential and commercial buildings, hotels use a high amount of resources in their operation, particularly electricity, water and gas. The findings suggest that strategies to reduce resource use are to be organised differently between electricity and water, with the former targeted at the hosts and the latter with the guests (MacAskill et al., 2023). Research with aim to design an econometric model of predicting spot electricity prices in Slovakia was conducted in V4 in 2020. The model of multiple linear regression can be used to predict the possible development of electricity prices depending on several relevant variables – coal prices, gas prices and the share of renewable energy sources. The data were obtained from Eurostat and OECD databases, investment sites, which showed the development of commodity prices on wholesale market, or from power exchanges or a short-term electricity market operator. The result was price forecasts for further periods, which were also compared with the actual spot prices (Andrejiova, et al., 2023).

5. Conclusion

This study analysed the relationship between energy costs, remuneration packages of employees and turnover of hotels and similar accommodation establishments in Czech Republic and Slovak Republic between 2007 and 2023. To carry out this analysis, we

approached the problem mathematically by constructing Dirichlet series to differentiate a function represented in table form. Our analysis utilized data from the Czech Republic and Slovakia between 2007 and 2023. Using this model, we assessed the impact of energy costs and employee remuneration on the turnover of accommodation establishments, as indicated by the accommodation services index in both countries. Economic instability caused fluctuations in wage and asset-based incomes, which subsequently affected the price levels of hotels and similar accommodation establishments, measured by the Average Daily Rate (ADR). Due to the restricted availability and accuracy of ADR data, complicated by trade secrets and limited willingness to disclose relevant information, the study used the index of hotels, similar accommodation establishments, and restaurants. Energy costs are simplified and funnelled to electricity costs collected with half year periodicity from 2007 and categorized as per average consumption (hotels with electricity consumption between 20 MWh to 1 999 MWh). Analysed was relationship between the Prices measured by Turnover index, in hotels and similar accommodations, and variables impacting costs including the Average wages and Energy costs of non-households in each respective country, specifically in the Czech Republic and Slovakia. We set two Hypothesis (H1). The results of this study confirmed Hypothesis 1 and is confirmed that the relationship between energy costs, remuneration packages of employees and turnover of hotels and similar accommodation establishments were found to be significant, with the statement considering the contribution of tourism sector to GDP performance. Hypothesis 2 (H2) about the negative association between the accommodation establishments' turnover and inflation ratio specifying that higher inflation in destination negatively influences tourism demand at all, including residents and turnover of accommodation establishment, is confirmed, however, there is a time lag between the maxima of the coefficient of elasticity of inflation according to the index of services and the index of inflation. The findings from this study contribute to a deeper understanding of the dependency dynamics between components of price setting strategy such as electricity prices and wages and accommodation prices, offering practical view on this field. Study did not observe further components of price setting strategy such as demand, competition or psychological motivation of customers, which might be valuable topic for further research.

Acknowledgments: This study was supported by the Internal Grant Agency (IGA) of FEM CULS in Prague, registration no. 2023A0007 GeoFigureical and economic segmentation and factors influencing consumer behaviour in the hotel services market.

Conflict of interest: none

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The Impact of Corporate Tax Rates on Economic Performance and Social Equity: Evidence from EU27

Vladimíra Hedvíka LACHEB* and Jana HINKE

University of West Bohemia, Pilsen, Czech Republic; vburesov@fek.zcu.cz; hinke@fek.zcu.cz

* Corresponding author: vburesov@fek.zcu.cz

Abstract: Corporate taxation plays a critical role in shaping economic and social outcomes within the European Union (EU). The aim of this article is to reveal similarities or connections between countries with similar tax rates based on long-term economic and social indicators. This study uses a frequency interval approach. EU27 countries were grouped into five frequency intervals based on corporate tax rate ranges, enabling a comparative analysis of their socioeconomic performance. Data for the period 2014–2023, sourced from OECD, Eurostat, and the World Bank, revealed distinct patterns: low-tax countries like Bulgaria and Cyprus attract investment but face challenges with income inequality, while moderate-tax economies such as Germany and Ireland balance competitiveness with equity. High-tax nations like Denmark and France emphasize social welfare and domestic stability, and outliers such as Malta demonstrate the potential of niche economic strategies. While lower corporate tax rates support FDI inflows and economic growth, they raise concerns about fiscal sustainability and social equity, aligning with previous studies on the trade-offs of tax competition. This study highlights the importance of coordinated tax policies to balance investment attractiveness with sustainable development and suggests directions for future research, including the integration of time-series data and effective tax rates.

Keywords: corporate taxation; tax competition; foreign direct investment (FDI); economic inequality; EU tax policy

JEL Classification: H25; F21; F23

1. Introduction

Corporate taxation plays a vital role in the fiscal policy of the European Union (EU), shaping both economic performance and social outcomes. Since the 1990s, EU member states have engaged in “tax competition,” where countries reduce corporate tax rates to attract foreign direct investment (FDI). This competitive approach has fostered economic activity, as lower tax rates have been shown to increase FDI inflows, stimulate domestic investment, create jobs, and boost government revenues (Devereux & Griffith, 2003; Raposo et al., 2020). Countries like Hungary and Ireland, known for their low corporate tax rates, have experienced significant FDI inflows that have contributed to rapid economic growth and employment (Akbar & McBride, 2004; de Abreu Pereira Uhr et al., 2023). However, the long-term implications of tax competition raise critical concerns about fiscal sustainability, social equity, and public sector financing.

While initiatives like the Common Consolidated Corporate Tax Base (CCCTB) and Anti-Tax Avoidance Directives (ATAD) aim to harmonize tax policies, significant differences in corporate tax rates persist across member states (European Commission, 2020). Lower tax rates can drive economic growth, but they also shift the tax burden to individuals, leading to income inequality and undermining social welfare systems (Fuest et al., 2018; Zucman, 2015). Furthermore, Mensah and Mensah (2021) highlight the economic volatility associated with FDI-driven growth, as multinational corporations may relocate to countries with more attractive tax incentives, destabilizing tax revenues in host countries. Ireland, for example, has drawn significant criticism for tax avoidance practices despite benefiting from FDI inflows. Studies such as those by Šimurina and Barbič (2017) and Lambert (2011) argue that tax cuts disproportionately benefit high-income individuals and large corporations, exacerbating income inequality and leaving governments to reduce social spending to remain competitive in global markets (Coady, 2018).

Much of the existing literature emphasizes the relationship between corporate tax rates and FDI. Clausing (2016) demonstrates a direct correlation between lower tax rates and higher FDI levels, while Becker et al. (2012) discuss how tax rates influence not just the quantity but the quality of FDI's contribution to local economies, particularly in terms of corporate tax revenue and labor income. The literature also highlights the need to consider broader economic implications. For example, Bezic et al. (2021) emphasize income tax rates as a key factor in attracting FDI, and Devereux et al. (2007) note that grants and subsidies have a limited impact on FDI decisions compared to tax rates. While countries like Ireland and Hungary have benefited from low taxes in attracting FDI, Zucman (2015) cautions that aggressive tax avoidance undermines governments' ability to collect revenue, contributing to fiscal deficits and rising inequality.

This debate extends to the broader implications of tax competition on public policy and social welfare. Tax competition forces governments to strike a balance between attracting investment and maintaining fiscal sustainability. For example, Fuest et al. (2018) point out that while tax cuts can spur short-term growth, they also increase pressure to cut public services or raise taxes on individuals, ultimately exacerbating social inequities. Similarly, Šimurina and Barbič (2017) argue that this dynamic undermines governments' ability to fund essential programs, further deepening inequality. The European Commission (2020) asserts that tax harmonization through initiatives like the CCCTB could mitigate harmful tax competition, ensuring fairer tax systems and fiscal transparency.

The aim of this article is to observe similarities or connections on the chosen indicators between the countries with similar tax rates based on long-term economic and social indicators. By analyzing these connections, the study seeks to understand whether countries with similar tax rates exhibit comparable economic and social outcomes, using data averaged over the period 2014-2023. Understanding these patterns is critical in evaluating whether low tax rates foster economic prosperity or exacerbate fiscal and social challenges. Given the EU's ongoing efforts to harmonize tax policies while ensuring social welfare, this analysis provides valuable insights into the broader implications of tax competition for economic growth, social equity, and fiscal sustainability.

2. Methodology

In this study, frequency intervals were used based on statutory corporate tax rate ranges, grouping EU27 countries into five frequency intervals. The primary goal was to group countries with similar corporate tax rates into intervals based on long-term trends rather than single-year values.

The frequency interval creation was based on the following steps:

1. Data selection: The corporate tax rates for all EU27 countries were collected as the primary feature for the analysis. To ensure a more reliable comparison, data for corporate tax rates was averaged over the period from 2014-2023. This provided a clearer view of tax policies over time, minimizing the impact of short-term fluctuations.
2. Range for frequency intervals: The tax rates were grouped into intervals with a range of 5%. This allowed for clear distinctions between frequency intervals while maintaining consistency in tax policies.
3. Frequency interval assignment: Countries were assigned to frequency intervals based on the similarity of their corporate tax rates. Countries within each interval were considered to have similar tax policies in the field of corporate tax.

After assigning countries to the five frequency intervals based on the adjusted corporate tax rates, the latest socioeconomic indicators were gathered to proceed with the comparative analysis. This approach involves systematically comparing the corporate tax rates across the EU27 countries based on the frequency intervals and descriptively analysing their impact on economic performance, FDI, and social equity. The study focuses on nominal corporate tax rates as the primary variable, but it also considers other factors such as FDI inflows, GDP, Gini Coefficient and unemployment rates.

The dataset used in the analysis includes adjusted long-term data for the period 2014–2023, sourced from the OECD (2024), Eurostat (2024), and World Bank (2024). Key variables include:

- Corporate Tax Rates (nominal rates in %), source OECD (2024), arithmetic average over the specified period;
- GDP (per capita, in EUR), source Eurostat (2024), geometric mean for the specified period;
- Foreign Direct Investment (FDI) (net inflows as a percentage of GDP) arithmetic mean for period of 10 years (2014–2023), source Worldbank (2024), median for the specified period;
- Unemployment Rates (percentage of the workforce), source OECD (2024), arithmetic average for the specified period;
- Income Inequality (measured by the Gini Coefficient), source OECD (2024), arithmetic average for the specified period.

The Gini coefficient is a measure of income inequality, with a score of 0 representing perfect equality and a score of 1 representing maximum inequality. The analysis reveals some interesting patterns in income inequality.

To mitigate the volatility associated with short-term data especially concerning the GDP and FDI the indicators over the period from 2014 to 2023 were used. The median was chosen for FDI adjustment. Using the median helps mitigate the impact of outliers and provides a clearer sense of the typical inflow of investment over time, without extreme values skewing the result. This approach provides a more stable and reliable view of how FDI has influenced long-term economic growth and performance, better reflecting the impact of sustained foreign investments rather than short-term spikes or dips. For GDP, the geometric mean was used as it accounts for compounded growth over time, capturing the long-term trend without being overly affected by short-term fluctuations or economic crises. In contrast, for unemployment rates, corporate income tax rates and the Gini coefficient, the arithmetic average was applied. These indicators are more stable and show steady trends over time, making the arithmetic mean an appropriate method to represent the typical level across the period without overemphasizing volatility.

The comparative analysis was performed based on the frequency intervals. To gain consolidated data, the data was grouped by interval, and medians for each variable were calculated across all countries within each interval. The median was chosen instead of the mean to reduce the impact of outliers.

The outcomes of the frequency interval-based analysis and comparative analysis were graphically visualized.

3. Results

Table 1 below provides a comprehensive overview of the adjusted key economic indicators for all 27 countries in the European Union, including corporate tax rates, GDP per capita, foreign direct investment (FDI) as a percentage of GDP, unemployment rates, and income inequality as measured by the Gini coefficient.

It provides insights into corporate tax rates and their relationship with key economic indicators across EU27 countries. GDP per capita varies widely, from Luxembourg (€102,893) and Ireland (€70,462) at the top to Bulgaria (€8,982) at the bottom, reflecting significant disparities in economic development.

FDI (% of GDP) also shows stark differences. Countries like Cyprus (33.31%) and Malta (28.06%) attract significant foreign investment, while others, such as Netherlands (-4.84%) and Belgium (-3.58%), face minor capital outflows.

Unemployment rates range from very low in Poland (4.69%) and Germany (3.77%) to exceptionally high in Greece (18.76%) and Spain (16.84%). These differences highlight varied labor market conditions across the region.

Finally, income inequality (Gini coefficient) is lowest in Slovenia (0.25) and Slovak Republic (0.23), suggesting more equitable income distribution, while Bulgaria (0.40) and Latvia (0.35) exhibit higher inequality, pointing to economic disparity within those nations.

Table 1. Comparative analysis EU27, own work based on data from OECD (2024), Eurostat (2024) and World Bank (2024)

Country	Corporate Tax Rate (%)	GDP (per capita, in EUR)	Foreign Direct Investment (FDI) (% of GDP) 10 years average	Unemployment Rate (%)	Income Inequality (Gini Coefficient)
Austria	24.90	43,625.79	-1.11	5.36	0.28
Belgium	29.00	41,210.87	-3.58	6.61	0.26
Bulgaria	10.00	8,982.49	3.30	6.24	0.40
Croatia	19.00	13,391.74	2.85	10.04	0.30
Cyprus	12.50	25,558.98	33.31	9.92	0.33
Czech Republic	19.00	20,514.24	3.74	3.25	0.25
Denmark	22.40	53,773.49	1.77	5.54	0.26
Estonia	20.10	20,419.54	6.57	6.08	0.32
Finland	20.00	42,432.21	5.28	7.87	0.27
France	33.58	35,544.84	1.73	8.80	0.29
Germany	15.83	41,834.49	1.88	3.77	0.29
Greece	25.60	17,238.20	1.83	18.76	0.32
Hungary	12.00	14,258.28	3.93	4.69	0.28
Ireland	12.50	70,462.86	17.35	6.81	0.29
Italy	25.05	30,006.56	1.26	10.24	0.33
Latvia	18.00	14,911.76	3.12	8.17	0.35
Lithuania	15.00	17,002.44	2.82	7.56	0.37
Luxembourg	19.80	102,893.44	20.80	5.73	0.31
Malta	35.00	27,879.47	28.06	3.97	0.30
Netherlands	25.16	47,097.04	-4.84	4.74	0.30
Poland	19.00	13,813.11	3.52	4.69	0.28
Portugal	29.40	19,856.20	3.47	8.59	0.32
Romania	16.00	10,827.26	2.88	6.22	0.35
Slovak Republic	21.30	17,051.40	2.14	8.03	0.23
Slovenia	18.40	22,302.98	3.03	6.01	0.25
Spain	25.80	25,627.43	2.70	16.84	0.33
Sweden	21.46	47,811.50	3.19	7.44	0.28

3.1. Incorporation of Key Indicators

The executed frequency interval analysis provides distinct groupings of EU27 countries that highlight variations in tax policies and their potential relationship with key economic indicators. Table 2 presents the results of the frequency interval analysis, categorizing EU27 countries into five groups based on corporate tax rate ranges. Interval 1 includes low-tax countries (10–14.9%), such as Bulgaria, Cyprus, Hungary, and Ireland, reflecting competitive tax policies. Interval 2 encompasses moderate tax rates (15–19.9%) in countries like Croatia, Czech Republic, Germany, Latvia, Lithuania, Luxembourg, Poland, Romania, and Slovenia, balancing competitiveness with revenue. Interval 3 represents tax rates of 20–24.9%, covering a mix of Central and Nordic countries like

Austria, Denmark, Estonia, Finland, Slovak Republic, and Sweden, characterized by stable economic structures. Interval 4 groups high-tax economies (25–29.9%) such as Belgium, Greece, Italy, Netherlands, Portugal, and Spain, typically advanced economies with strong public welfare systems. Finally, Interval 5 includes outliers like France and Malta, with tax rates in the range of 30–35%.

Frequency Interval	Tax Rate Range (%)	Countries
1	10–14.9	Bulgaria, Cyprus, Hungary, Ireland
2	15–19.9	Croatia, Czech Republic, Germany, Latvia, Lithuania, Luxembourg, Poland, Romania, Slovenia
3	20–24.9	Austria, Denmark, Estonia, Finland, Slovak Republic, Sweden
4	25–29.9	Belgium, Greece, Italy, Netherlands, Portugal, Spain
5	30–35	France, Malta

Table 2. Segmentation of EU27 by corporate tax rate intervals (%)

Figure 1 shows the median values for each economic indicator across the five intervals based on corporate tax rate ranges. The first plot illustrates the Median GDP (per capita, in EUR) by Interval. Interval 3 (17–23%) has the highest median GDP of EUR 45,995, reflecting the economic strength of countries such as Germany, Sweden, and Finland, which are characterized by stable economies and high levels of industrial development. In contrast, Interval 1 (10–14.9%)—which includes Bulgaria, Cyprus, Hungary, and Ireland—has the lowest median GDP of EUR 14,690, highlighting the challenges faced by these countries despite their low tax rates. These low-tax economies, while competitive, still struggle to drive high economic output, suggesting that other factors, such as infrastructure quality and institutional stability, are critical in shaping long-term GDP growth.

The second plot, Median FDI (% of GDP) by Interval, reveals stark contrasts in foreign direct investment (FDI) flows. Interval 5 (30–35%), driven primarily by Malta, has the highest median FDI of 14.75%, highlighting Malta’s exceptional position as a financial hub that attracts substantial foreign capital. In contrast, Interval 1 (10–14.9%) shows a much lower median FDI of 3.30%, suggesting that countries like Bulgaria and Cyprus with lower tax rates do not necessarily retain or attract substantial investment relative to their GDP. Intervals 2 (15–19.9%) and 3 (17–23%) show more balanced but moderate FDI inflows of around 2–3%, suggesting that countries with moderate tax rates can maintain stability without dramatic foreign investment increases.

The third plot, Median Unemployment Rate (%) by Interval, shows that Interval 4 (24–26%) has the highest median unemployment rate of 8.35%, likely influenced by high-tax countries such as Greece and Spain, which are grappling with labor market challenges.

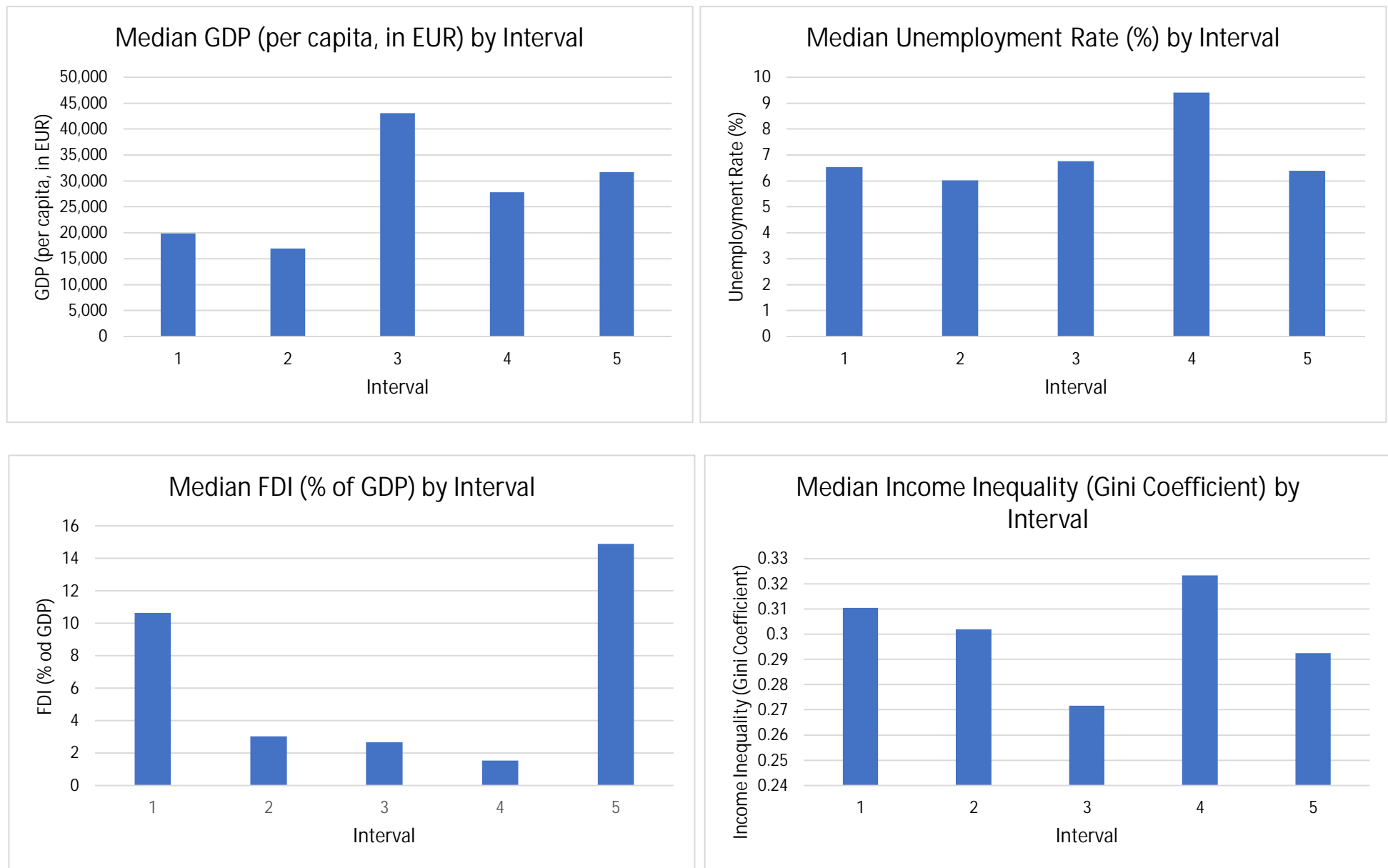


Figure 1. Median of indicators for each interval

In contrast, Interval 1 (10–14.9%)—consisting of Bulgaria, Cyprus, Hungary, and Ireland—has the lowest median unemployment rate of 4.21%, suggesting more stable labor markets in these low-tax economies. Intervals 2 (15–19.9%) and 3 (17–23%) show moderate unemployment rates, reflecting how tax policies can influence labor market conditions but are not the sole determining factor.

The fourth plot, Median Income Inequality (Gini Coefficient) by Interval, shows that Interval 4 (24–26%) has the highest median Gini coefficient of 0.32, indicating that high-tax economies may struggle to address inequality despite their wealth redistribution efforts. In contrast, Interval 1 (10–14.9%) has a lower median Gini coefficient of 0.28, suggesting relatively more equitable income distribution in these economies. However, this lower inequality in Interval 1 might reflect the challenges these countries face in developing higher-value industries rather than being an outright success of low taxes. Interval 3 (17–23%) shows a Gini coefficient of 0.29, indicating a more balanced approach to economic growth and income distribution, where moderate tax rates are used to fund robust welfare systems while keeping inequality at reasonable levels.

In summary, the analysis using frequency intervals based on corporate tax rates reveals distinct patterns in the relationship between tax policies and key economic outcomes. Interval 3 (17–23%) emerges as the wealthiest group, with a high median GDP, suggesting that moderate tax rates support strong economic performance without significant trade-offs. Interval 5 (30–35%), driven by Malta, demonstrates the potential for high tax rates to still attract substantial FDI, primarily due to the country's niche financial sector. Interval 1 (10–14.9%) shows lower GDP and FDI but also features the most stable unemployment and relatively low-income inequality, suggesting that these economies benefit from a focus on equitable growth. Interval 4 (24–26%) represents high-tax economies that prioritize social welfare and stability but face challenges with higher unemployment and moderate-income inequality. This highlights the ongoing tension between using tax policy to drive social equity and economic growth. The frequency interval approach provides valuable insights into the complexities of balancing competitiveness, equity, and fiscal sustainability across different EU regions.

4. Discussion

This study contributes to the ongoing debate on the impact of corporate tax rates on economic and social outcomes within the EU27. The frequency interval analysis identified five distinct groups of countries based on tax rate ranges, highlighting how variations in tax rates correspond to differences in GDP, FDI, unemployment, and income inequality. These findings align with previous studies, such as those by Devereux and Griffith (2003), who emphasize the role of tax rates in attracting FDI, and by Zucman (2015), who highlights the risks of tax avoidance and inequality in low-tax regimes.

The results demonstrate that low-tax countries, such as Bulgaria and Cyprus in Interval 1 (10–14.9%), often rely on tax competition to attract FDI, consistent with studies by Akbar and McBride (2004) and Raposo et al. (2020). However, the relatively low median GDP and moderate FDI inflows, coupled with high-income inequality observed in this interval,

suggest that low tax rates alone do not guarantee sustained economic growth or equitable wealth distribution. This supports the concerns raised by Fuest et al. (2018), who warn that tax competition may shift the tax burden to individuals, exacerbating inequality and undermining fiscal sustainability. Countries in Interval 2 (15–19.9%), such as Germany and Ireland, achieve a balance between competitiveness and equity. The stable FDI inflows and moderate inequality observed in this interval resonate with the findings of Clausing (2016), who demonstrates a positive correlation between moderate tax rates and FDI-driven growth. Ireland, with its targeted tax policies, exemplifies how such strategies can attract multinational corporations while stabilizing domestic economic performance. However, as Mensah and Mensah (2021) point out, over-reliance on FDI can create vulnerabilities to global capital shifts, raising concerns about long-term stability.

Interval 3 (17–23%) highlights the success of moderate-to-high tax rates in fostering equitable economies with strong welfare systems. The Nordic countries within this interval, such as Sweden and Finland, exemplify the findings of Šimurina and Barbič (2017), who argue that redistributive fiscal policies mitigate inequality and promote social equity. Luxembourg, with its high GDP and active FDI inflows, illustrates how niche financial hubs can drive growth. This interval underscores the capacity of higher tax revenues to fund robust social and economic systems while maintaining global competitiveness.

Interval 4 (24–26%), representing high-tax economies like Denmark and Portugal, reflects advanced industrialized nations prioritizing social welfare and internal development. The modest FDI inflows in this interval suggest that high tax rates may reduce their attractiveness to foreign investors, supporting concerns raised by Coady (2018) about the trade-offs between tax revenues and investment. However, the strong redistributive policies observed in this interval highlight the benefits of leveraging tax revenue for social stability and equity.

Interval 5 (30–35%), comprising Malta and France, presents contrasting economic strategies. Malta's high FDI inflows, driven by its role as a financial center, align with the findings of Becker et al. (2012), who emphasize the role of niche economies in attracting quality investments. France, with its broader economic base, highlights a more traditional path to stability. Both countries illustrate the diversity of strategies employed by EU member states to balance tax policy with economic outcomes.

This study is subject to several limitations. First, the analysis focuses on nominal corporate tax rates and does not account for effective tax rates, which could provide a more nuanced understanding of tax policies. Second, the study relies on median values across the intervals, which, while reducing the impact of outliers, may obscure individual country dynamics within each interval. Lastly, the study does not consider non-tax factors, such as infrastructure, governance, or market size, that also influence FDI and economic outcomes.

Future research could address these limitations by incorporating time-series data to explore the dynamic effects of tax policies over time. Expanding the scope to include effective tax rates and non-tax factors would provide a more comprehensive view of the determinants of economic performance.

5. Conclusions

This study demonstrates how corporate tax rates influence economic and social outcomes across the EU27, revealing distinct patterns of GDP, FDI, unemployment, and income inequality within each frequency interval. Low-tax countries struggle with income inequality and investment retention, while moderate- and high-tax economies achieve a balance between growth and social equity. Outliers like Malta show how niche economic strategies can drive exceptional outcomes, such as high FDI inflows despite relatively high tax rates. While tax competition fosters investment, it also raises concerns about fiscal sustainability and social equity. Addressing these challenges requires coordinated efforts to balance competitiveness with the need for sustainable and inclusive economic policies that ensure long-term stability and growth.

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Conflict of interest: none

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Disparities in Residential Unit Prices: An Econometric Analysis of Housing Markets in Prague and Ústí nad Labem

Jakub LISA and Stanislav ŠAFRÁNEK

University of Hradec Kralove, Hradec Kralove, Czech Republic; jakub.lisa@uhk.cz; stanislav.safranek@uhk.cz

* Corresponding author: jakub.lisa@uhk.cz

Abstract: This study examines the disparities in residential unit prices between Prague and Ústí nad Labem using econometric analysis. Data was collected from the Czech real estate platform srealty.cz between October 2023 and January 2024. The research applies ANOVA (Analysis of Variance) to investigate the influence of three key factors—location, apartment condition, and equipment—on unit price per square meter. The findings reveal significant differences in the impact of these factors between the two cities. In Prague, all three factors show a statistically significant effect on unit prices, whereas in Ústí nad Labem, only location and equipment play a notable role. The study underscores the importance of regional market characteristics in real estate valuation and suggests that price determinants are highly dependent on the socio-economic and infrastructural conditions of each city. The results provide valuable insights for investors, urban planners, and policymakers in understanding regional housing market dynamics.

Keywords: real estate prices; housing market; econometric analysis; regional disparities; price differentiation; housing price determinants

JEL Classification: C21; R12; R31

1. Introduction

Prague is generally considered the most expensive city in the Czech Republic. Prague is divided into 57 city districts. Among the 57 urban districts, there are four largest urban districts with a population of around 100,000, namely Prague 4 (largest population – 129,150), Prague 10 (107,317 inhabitants), Prague 8 (99,356 inhabitants) and Prague 6 (98,985 inhabitants). Prague attracts many people for work, especially from the surrounding municipalities, but it is not an exception that employees commute to Prague more than 50 km a day. There is an increased demand for all real estate in Prague. Prague has a well-crafted spatial plan, where the areas for its development are clearly indicated (Institut plánování a rozvoje hlavního města Prahy, 2024). New buildings are being built in most of Prague, and original buildings are being reconstructed in the historic parts of the city. The city also has a rich social and cultural life, with a number of restaurants offering traditional Czech cuisine, cafes and pubs where visitors can enjoy the famous Czech beer, which is why Prague is a sought-after city from the point of view of tourists and foreign investors who buy real estate for further rental (Prague for all, 2024).

In contrast, the city of Ústí nad Labem is located in the northern part of the Czech Republic, located at the confluence of the Elbe and Bílina rivers. The main sights of the city are, for example, the baroque Vetruse Castle, which provides a panoramic view of the city and the surrounding countryside, the Gothic Church of the Exaltation of the Holy Cross, which dominates the historic centre of the city, as well as a number of other historic buildings and monuments. Ústí nad Labem is less desirable in terms of housing, the reason being the fact that there are socially excluded locations in the city. Ústí nad Labem is one of the cheapest regional towns in the Czech Republic. The economy of Ústí nad Labem is based on industry, mainly chemical and engineering. Foreign tourists rarely visit Ústí nad Labem (Ústí nad Labem, 2020).

2. Methodology

The data was collected from the real estate server www.sreality.cz. The reason for choosing this server was the fact that it is the largest Czech real estate portal, where real estate of all kinds is offered for sale, especially in the Czech Republic. Currently, more than 90 thousand are advertised on the [sreality.cz](http://www.sreality.cz) server. advertisements, of which more than 17 thousand apartments for sale and more than 11 thousand ads for rent throughout the Czech Republic. The data was collected from October 2023 to January 2024, for the territory of the capital. Prague and Ústí nad Labem. These two cities were chosen as representative to which the research is applied. Cities are very different in character, so it seems statistically appropriate to implement the mentioned hypotheses on them. Prague, the capital of the Czech Republic, is the historical and cultural center of the country. It is located on the Vltava River and is famous for its architecture, including medieval walls, Baroque churches, Gothic cathedrals and Renaissance palaces. One of the most important symbols of Prague is Prague Castle, an impressive complex including the Gothic cathedral of St. Vita, the Old Royal Palace and the Basilica of St. George (Sreality, 2024).

In conference paper will be use ANOVA (Analysis of Variance). This statistical method is used for comparisons of mean values of multiples groups in order to find out whether there is a significant statistical difference between them. The main purpose of ANOVA is to determine if the variability between the groups is greater than the variability within the groups, which would suggest that the mean values of groups vary. ANOVA was used to assess the differences between the groups based on nonnumerical variables such as the condition and equipment of the apartment. ANOVA allows us to determine whether there are statistical differences between these groups (Field, 2017). This method is useful in that it allows us to test the hypothesis of differences between the groups and thus answer the research question. ANOVA is commonly used for such purposes, for example:

- Analysis on the real estate prices: A perspective of spatial correlation with shopping district (Tsai et al., 2012).
- The effect of listing price strategy on real estate negotiations: An experimental study (Cardella & Seiler, 2016).
- Valuation of Real Estate: A Multiple Regression Approach.

- The use of hedonic pricing method to determine the parameters affecting residential real estate prices.
- Wind power and real estate prices in Oklahoma (Castleberry & Greene, 2018).

Table 1. Sample of processed data for Prague (100 samples)

No.	Floor area (m2)	Price (CZK)	Unit price (CZK)	Location	Apartment condition	Equipment
1	31	6,350,000.00	204,838.71	1	2	2
2	32	7,950,000.00	248,437.50	1	1	2
3	30	4,590,000.00	153,000.00	2	3	2
...
99	154	15,500,000.00	100,649.35	2	3	3
100	100	16,980,000.00	169,800.00	2	2	2

Table 2. Sample of processed data for Ústí and Labem (45 samples)

No.	Floor area (m2)	Price (CZK)	Unit price (CZK)	Location	Apartment condition	Equipment
1	32	1,090,000.00	34,062.50	2	2	2
2	36	1,130,000.00	31,388.89	2	2	2
3	32	859,000.00	26,843.75	3	2	2
...
44	83	2,150,000.00	25,903.61	3	2	3
45	85	3,090,000.00	36,352.94	2	2	2

Praha will be designated within the city as 1 and Usti nad Labem will be designated as 2. As part of the statistical investigation, sub-attributes of each analyzed ad that influence the value of the property were analyzed (Table 1 and 2).

The attribute was:

- Location,
- Condition of the apartment,
- Equipment apartment.

Each attribute was rated on a scale from 1 to 3, where A value of 1 means good; 2 = average; 3 = wrong. Each property was visually assessed and assigned a point rating. Textually, the values are as follows:

Localities

- 1 = good (near public transport, shops, suitable for renting, quiet part, no negative factors)
- 2 = average (ordinary places, suitable for living, ordinary surroundings, minimal influence of negative factors)
- 3 = bad (busy location, worse location for renting, far from public transport, negative factors)

Condition of the apartment:

- 1 = good (new building or after reconstruction),
- 2 = average (older house, routine maintenance),
- 3 = bad (negligent maintenance, before renovation).

Apartment equipment:

- 1 = good (new apartment or after reconstruction),
- 2 = average (older apartment, routine maintenance),
- 3 = bad (obsolete, unsuitable or missing - suitable for modernization).

3. Results

The primary objective of this research is to analyze whether the price per square meter of residential units varies depending on the city in which the apartment is located, specifically comparing Prague and Ústí nad Labem. The problem is formulated through a set of hypotheses that examine the relationship between the unit price and key factors such as location, apartment condition, and equipment.

Hypothesis 1

- H_0 : The relationship between the unit price and other variables (apartment condition, equipment, location) is the same in Prague as in Usti nad Labem.
- H_A : The relationship between unit prices and other variables differs between Prague and Usti nad Labem.

Hypothesis 2

- H_1 : Location, condition of the apartment and equipment have a statistically significant influence on the price of an apartment in Prague.
- H_A : At least one of the investigated variables does not statistically have a significant effect on the price of an apartment in Prague.

Hypothesis 3

- H_2 : The location, condition of the apartment and equipment have a statistically significant effect on the price of an apartment in Usti and Labem.
- H_A : At least one of the investigated variables does not statistically have a significant effect on the price of an apartment in Usti nad Labem.

3.1. Hypothesis 1

The prices of housing units can vary depending on various factors such as location, condition of the dwelling and its amenities. This hypothesis aims to analyse whether the relationship between price per square metre and these variables remains the same in Prague and Ústí nad Labem, or whether there are statistically significant differences between the two housing markets.

Table 3. Model summary of Hypothesis 1

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.395 ^a	.156	.138	71,199.810

a. Predictors: (Constant), Localities, Condition of the apartment, Apartment equipment

Regressive analysis was conducted to examine the influence of variable factors on the unit price of apartments. The model has a value of R square 0.156 which means that roughly 15.6 % of the unit price variability is linked to independent variables in the model (Table 3). Despite the relatively low value, it suggests that the selected variables have a certain influence on the unit price.

Table 4. ANOVA^{a, b} of Hypothesis 1

Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	131,787,929,236.642	3	43,929,309,745.547	8.666
	Residual	714,787,229,678.610	141	5,069,412,976.444	
	Total	846,575,158,915.252	144		

a. Dependent Variable: Unit price

b. Predictors: (Constant), Localities, Condition of the apartment, Apartment equipment

Table 5. Coefficients^a of Hypothesis 1

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	256,918.485	32,081.688		8.008	<.001
	Location	-24,475.088	10,949.250	-.197	-2.235	.027
	Condition	651.758	15,626.022	.004	.042	.967

a. Dependent Variable: Unit price

The results of ANOVA (variance analysis) show that the regressive model as a whole is statistically significant ($F = 8.666$, $p < 0.001$) (Table 4). This means that the model as a whole is capable of providing a better explanation of the variance than a coincidence. This result supports the argument to use regressive data analysis. The location coefficient is -24,475.088, which suggests that the worse location (higher value of the category) translates in lower unit price (Table 5). This coefficient is statistically significant ($p = 0.027$), therefore the location affects significantly the unit price. The coefficient for the condition of apartment is 651.758 which could suggest that better condition (lower value of the category) translates in positive impact on unit price. However, this coefficient is not statistically significant ($p = 0.967$) which means that the condition of the apartment has not a significant effect on unit price in this particular model. The coefficient for equipment is -40,129.530 which means that worse equipment (higher category value) leads to lower unit price. This coefficient is statistically significant ($p = 0.002$) and therefore the equipment affects significantly the unit price.

3.2. Hypothesis 2

The housing market in Prague is characterised by high demand and relatively stable house prices. This hypothesis examines whether there is a statistically significant effect of location, condition of the dwelling and its amenities on the price per square metre within Prague, which could provide investors and professionals with important information on the factors influencing property prices in the capital.

Table 6. Model summary of Hypothesis 1

Model	R Location = 1	R Square	Adjusted R Square	Std. Error of the Estimate
1	.716 ^a	.513	.498	31,838.402

a. Predictors: (Constant), Localities, Condition of the apartment, Apartment equipment

Regressive analysis for Prague (Table 6) provided a model's value R square 0.513 which means that approximatively 51.3 % of the variance is given by independent variables (condition of the apartment, equipment, location). This result implies that selected variables have a significant effect on unit prices in Prague.

Table 7. ANOVA ^{a, b, c} of Hypothesis 2

Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10,251,813,440.390	3	34,172,711,468.463	33.711
	Residual	97,313,647,985.593	96	1,013,683,833.183	
	Total	199,831,782,390.983	99		

a. Dependent Variable: Unit price

b. Selecting only cases for which Location = 1

c. Predictors: (Constant), Localities, Condition of the apartment, Apartment equipment

Table 8. Coefficients^{a, b} of Hypothesis 2

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	344,359.680	17,613.599		19.551	<.001
	Localities	-24,922.822	5,528.249	-.355	-4.508	<.001
	Condition of the apartment	-37,017.034	8,353.753	-.341	-4.431	<.001
	Apartment equipment	-23,715.193	6,844.442	-.268	-3.465	<.001

a. Dependent Variable: Localities, Condition of the apartment, Apartment equipment

b. Selecting only cases for which Location = 1

The ANOVA results (Table 7) show that the regressive model as a whole is statistically significant ($F = 331,711$, $p < 0.001$). That means the model itself is capable of explaining the variance in unit price better than coincidence. This result supports the use of regressive analysis for Prague data. Coefficient for location is -24,922.822 which suggests that worse location (higher value of the category) leads to lower unit price (Table 8). This coefficient is statistically significant ($p < 0.001$). Therefore, the location has a significant effect on unit price. The coefficient for the condition of the apartment is -37,017.034 which implies that worse condition of an apartment (higher value of the category) leads to lower unit price. This coefficient is statistically significant ($p < 0.001$) which means that the condition of the apartment has significant effect on the unit price. Coefficient for equipment is -23,715.193 which suggests that worse equipment (higher value of the category) leads to lower unit price. This coefficient is statistically significant ($p < 0.001$) which means that the equipment affects significantly the unit price.

The results for Prague show that all three variables (location, condition of apartment, equipment) have a statistically significant impact on the unit price. This suggests that the quality and equipment of an apartment as well as its location in terms of Prague are key factors affecting the price per square meter. The hypothesis „H1: Location, condition of apartment and equipment have statistically significant effect on the price of an apartment in Prague“ cannot, therefore, be rejected.

3.3. Hypothesis 3

Ústí nad Labem is characterised by a different structure of the housing market compared to Prague, while the prices of flats remain relatively low. This hypothesis focuses on whether the location, condition of the apartment and its amenities have the same influence on housing prices in this city as in Prague, or whether some factors are different.

Table 9. Model summary of Hypothesis 3

Model	R Location = 1	R Square	Adjusted R Square	Std. Error of the Estimate
1	.737 ^a	.543	.509	5,697.087

a. Predictors: (Constant), Localities, Condition of the apartment, Apartment equipment

Regressive analysis for Usti nad Labem (Table 9) shows that the model has a value of R square 0.543 which means that approximatively 54.3 % of variance in unit price is explained by independent variables (condition of the apartment, equipment, location). This result suggests that selected variables have significant effect on unit price in Usti nad Labem.

Table 10. ANOVA ^{a, b, c} of Hypothesis 3

Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1,578,167,992.508	3	526,055,997.503	16.208
	Residual	1,330,729,019.463	41	32,456,805.353	
	Total	2,908,897,011.971	44		

a. Dependent Variable: Unit price

b. Selecting only cases for which Location = 2

c. Predictors: (Constant), Localities, Condition of the apartment, Apartment equipment

Table 11. Coefficients^{a, b} of Hypothesis 3

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	61,401.681	4,432.033		13.854	<.001
	Location	-6,533.570	1,896.759	-.452	-3.445	.001
	Condition	-637.226	2,389.477	-.033	-.267	.791
	Equipment	-5,556.332	1,903.645	-.371	-2.919	.006

a. Dependent Variable: Localities, Condition of the apartment, Apartment equipment

b. Selecting only cases for which Location = 2

The ANOVA results (Table 10) show that the regressive model as a whole is statistically significant ($F = 16.208$, $p < 0.001$). That means the model itself is capable of explaining the

variance in unit price better than coincidence. This result supports the use of regressive analysis for data from Ústí nad Labem. Coefficient for location is -6,533.570 which suggests that worse location (higher value of the category) leads to lower unit price (Table 11). This coefficient is statistically significant ($p = 0.01$). Therefore, the location has a significant effect on unit price. The coefficient for the condition of the apartment is -637.226 which implies that worse condition of an apartment (higher value of the category) leads to lower unit price. However, this coefficient is not statistically significant ($p = 0.791$), which means that the condition of the apartment does not have a significant effect on the unit price in this particular model. Coefficient for equipment is -5,556.332 which suggests that worse equipment (higher value of the category) leads to lower unit price. This coefficient is statistically significant ($p = 0.006$) which means that the equipment affects significantly the unit price. Based on these findings, it is possible to reject the hypothesis „H1: Location, condition of apartment and equipment have statistically significant effect on the price of an apartment in Usti nad Labem“ and embrace a different hypothesis

4. Discussion and Conclusion

While the proposed model has several limitations, it still provides a valuable basis for comparing residential unit prices between Prague and Ústí nad Labem. One key drawback lies in the subjective interpretation of non-numerical factors, such as apartment condition, equipment, and location, which may introduce bias into the analysis. Additionally, the lack of nuanced data—where categorical attributes are assigned fixed numerical values (e.g., 1, 2, 3) rather than allowing for fractional distinctions—can reduce the model's precision. Another concern is data representativeness, as property listings are collected within a specific timeframe, meaning that market fluctuations outside this period may not be reflected in the results. Furthermore, the varying number of listings per city could impact the accuracy of statistical comparisons. Differences in how real estate agents present property information may also affect consistency, as descriptions and categorizations are not standardized. Lastly, the gap between advertised and actual purchase prices poses a challenge, given that listing prices are often inflated compared to real transaction values.

Despite these limitations, the model remains a useful tool for comparative analysis. By maintaining consistent classification criteria across both cities and focusing on overall trends rather than absolute values, it allows for an insightful evaluation of price determinants. While results should be interpreted with caution, particularly regarding absolute price levels, the comparative relationships between influencing factors can still provide meaningful conclusions for investors, policymakers, and market analysts.

The statistical analysis revealed that selected factors influence apartment prices differently in Prague and Ústí nad Labem. Specifically, apartment condition has a statistically significant impact on prices in Prague but not in Ústí nad Labem. This finding suggests that the relationship between particular variables differs between the two cities. Consequently, the null hypothesis (H_0) can be rejected, confirming that there is a significant difference in price per square meter based on the city of location.

Moreover, the statistical analysis did not confirm that apartment prices follow a uniform pattern based on condition, location, and equipment. As a result, prices of one apartment cannot be precisely determined based on the prices of others with similar characteristics. For example, in a given location, it is not necessarily the case that a one-bedroom apartment is x -times more expensive than a two-bedroom apartment. Instead, pricing varies across locations and apartment types, reflecting complex market dynamics.

Conflict of interest: none

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Profit and Cash-Flow of the Transmission System Operators Interconnected with the Czech Electricity Grid

Enikő LŐRINCZOVÁ*, Jitka ŠIŠKOVÁ, Ivana KUCHAROVÁ and Daniela PFEIFEROVÁ

Czech University of Life Sciences Prague, Prague, Czech Republic; lorinczova@pef.czu.cz; siskova@pef.czu.cz; kucharova@pef.czu.cz; pfeiferova@pef.czu.cz

* Corresponding author: lorinczova@pef.czu.cz

Abstract: Transmission system operators (TSOs) manage the transmission of electricity via high-voltage long distance power grids. In the Czech Republic, the sole TSO is ČEPS (Česká elektroenergetická přenosová soustava). The aim of the paper is to investigate whether ČEPS and the directly interconnected cross-border TSOs achieved profit and positive cash-flow in the previous years. Methodology is based on the relevant legal and other sources and the published annual reports of 6 selected TSOs, namely ČEPS (the sole TSO in the Czech Republic), TenneT (NL, Germany), 50Hertz (Germany), APG (Austria), SEPS (the sole TSO in Slovakia) and PSE (the sole TSO in Poland), for years 2019-2023. Observing the reporting of these companies, several main things are obvious: 1. In many EU countries the TSOs are natural monopolies and are regulated by authorities which determine the cap on the revenues, what the TSO can charge in grid fees, thus influencing the profit. 2. The overall cash-flow can be positive due to big borrowings. 3. Investments are ongoing or planned as new technologies are needed to absorb the increasing input of renewable energies into the grid from diverse sources. 4. Accounting standards used for preparing the financial statements influence the reported revenues and profit.

Keywords: transmission system operator TSO; electricity; financial reporting; profit; cash-flow

JEL Classification: M41; Q40; X02

1. Introduction

The electric grid is a network connecting electricity generators and consumers via the transmission and distribution networks. Transmission networks are networked grids of long-distance power lines with high voltage and are run by transmission-system operators (TSOs). The European transmission grid contains more than 300,000 km of power lines, including 355 cross-border lines. (Erbach, 2016). A transmission system operator is part of the electricity flow supply chain (shown in Figure 1). The tasks of a transmission system operator are defined by the Directive 2019/944/EU on the common rules for the internal market for electricity, in Chapter V, Article 40. The cooperation within the European market with electricity is helped

and coordinated by the European Transmission System Operators for Electricity (ENTSO-E) and the European Agency for the Cooperation of Energy Regulators (ACER).

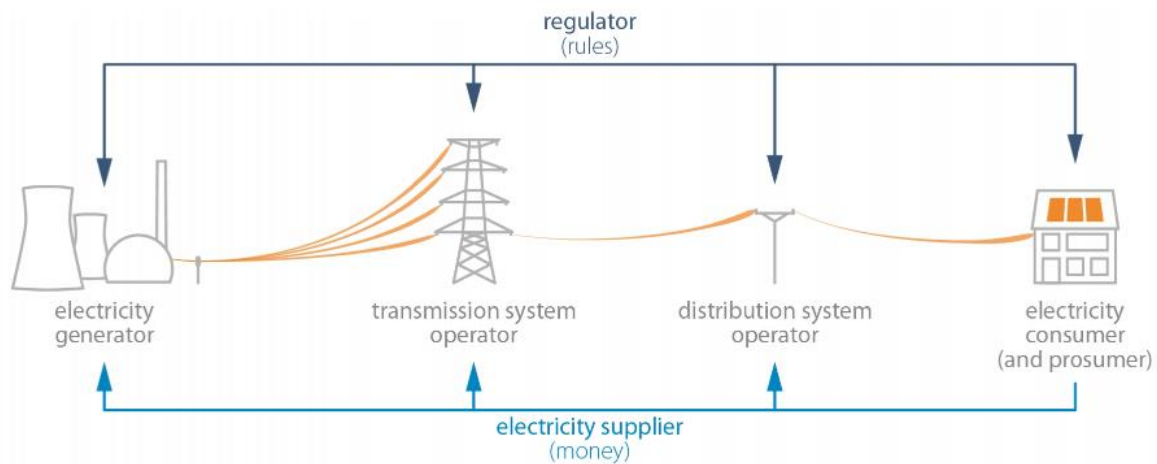


Figure 1. Simplified view of the process of the electricity flow and the role of the TSO (Erbach, 2016)

ENTSO-E (European Transmission System Operators for Electricity) represents 40 members from 36 countries and 2 observer members (Moldova and Turkey) (ENTSO-E, 2024). As the Appendix 1 shows, Germany and Austria have the most TSOs, 4 and 2 respectively. In the Czech Republic, ČEPS (Česká elektroenergetická přenosová soustava) is the sole Czech Transmission System Operator. The directly interconnected cross-border transmission systems to the Czech electricity grid are shown in Figure 2.

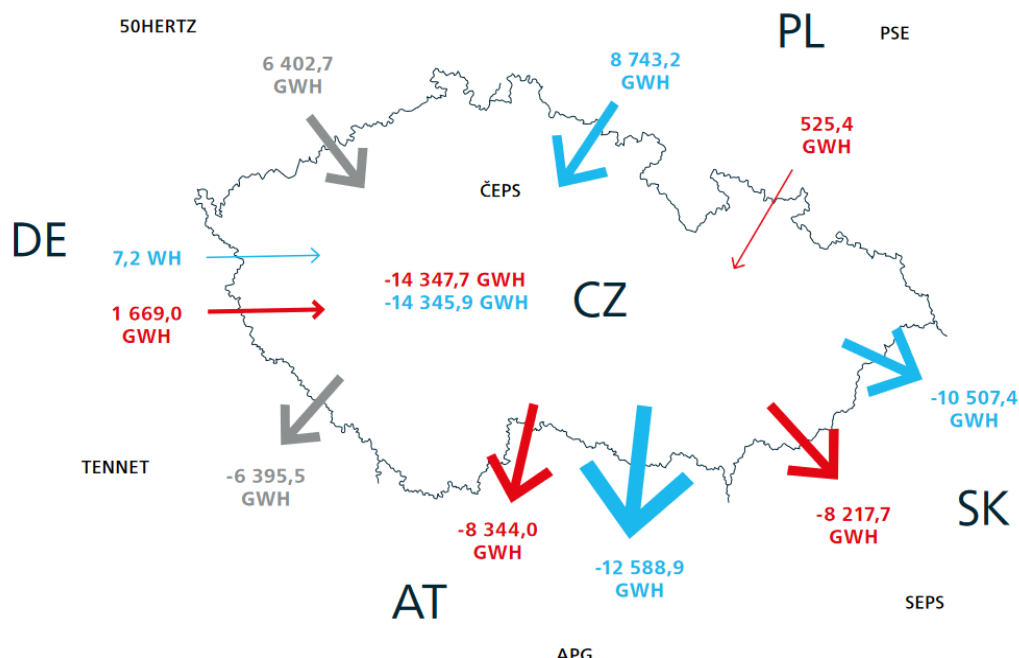


Figure 2. Interconnected grid example of planned (red) and actual (blue) cross-border electricity flows on 15. 2. 2022 at 7am (ČEPS annual report, 2022)

ACER (the Agency for the Cooperation of Energy Regulators, established in 2011) helps to coordinate the cross-border regulation of electricity and the cooperation of the national regulatory authorities and oversees the methodology of the revenue (price) caps calculations

of the member states. Directive 2019/943/EU states that the level of the tariffs applied to producers or final customers, or both should take into account the amount of network losses and congestion caused, and investment costs for infrastructure.

The regulated components of the electricity price paid by the end customers in the Czech Republic is regulated by the authority ERÚ (Energetický regulační úřad) and sets the mechanism of price regulation for charges related to the fee of the transmission system operator (ČEPS), the fee of the distribution system (ČEZ Distribuce, E.ON Distribuce and PREdistribuce), the fee of the market operator (OTE, operator trhu s elektřinou) and also the fee for supported energy sources from renewable energy. Transmission fees include for example a charge for reserved transmission system capacity, a charge for using the transmission system network, covering losses in the system, charges for system services. Electricity distribution fees include charges for reserved capacity and charge for using the distribution system networks (ERÚ, 2020).

Voltage problems may arise in both transmission and distribution grids due to the uncertain production of renewable energy sources. (Rodrigues et al., 2023). Distribution system operators and transmission system operators will have to redefine the coordination of operational roles and responsibilities regarding the distributed energy resource operations (Morais Valente et al., 2021). As Jansen (2022) stated, the changing electricity generation resources and the emerging sources of renewable energy from diverse sources (wind, solar, hydro) pose huge challenges to the transmission systems and TSOs, increasing the need of investments into new technologies and revision of the energy policies.

Historically, the electricity system was dominated by monopolies with large centralised nuclear or fossil fuel power plants (Directive 2019/943/EU). Greer (2022) discusses if the electricity industry is a natural monopoly and concludes that yes (the transmission and distribution parts), as there are high fixed costs which are mostly sunk, as the assets are specific and not easily sold, also discussing if it would be possible to entry a state controlled natural monopoly, cover the entry costs and earn a normal profit? Greer says the obvious answer is likely no.

2. Methodology

Methodology is based on data collection from the relevant legal and other sources and the published annual reports of the selected 6 TSOs (transmission system operators), namely ČEPS (Česká elektroenergetická přenosová soustava, the sole TSO in the Czech Republic) and the cross-border interconnected TSOs: TenneT (NL and Germany), 50Hertz (Germany), APG (Austrian Power Grid, Austria), SEPS (Slovenská elektrizačná prenosová sústava, the sole TSO in Slovakia) and PSE (Polskie Sieci Elektroenergetyczne, the sole TSO in Poland) for years 2019 - 2023. The TSOs were selected based on their direct connection to the Czech electric grid, shown in Figure 2. The basic characteristics of the TSOs are shown in Table 1.

For data collection, the published consolidated financial statements of the TSOs were used. The data about the development of the revenues and profit were collected from the Income statements, data about the cash-flow development were collected from the Cash-flow statement. The data about the paid out dividends were collected from the financial cash-flow

and were cross-checked with the Statement of changes in equity. For investment activity, the investment cash-flow and the annual reports were investigated. For further information the Notes to the financial statements and the annual report information were searched by keywords. The published financial statements of the TSOs were prepared mostly by different accounting standards, using a different reporting currency and presentation of the amounts. The paper used the presented amounts without change. Losses or other negative amounts are presented in brackets.

3. Results

The characteristics of the selected transmission system operators about the year of foundation, the ownership, the legal form, the length of the electric grid and the national regulator authorities are shown in Table 1.

Table 1. Basic characteristics of the selected transmission system operators (TSOs) (annual reports, 2023)

TSO	Country	Owner	Founded	Legal form	Grid	Regulator
ČEPS	Czech Republic (CZ)	The Czech Republic 100 % (Ministry of Industry and Trade)	1998	Joint-stock company	5,848 km	Energetický regulační úřad ERÚ
50Hertz	Germany (DE)	Elia Group (80%) KfW Bank Group (20%) (via Eurogrid)	2002	GmbH company with limited liability	10,658 km	Bundesnetzagentur BNetzA
TenneT	Netherlands and Germany (NL, DE)	Dutch Government 100% (Ministry of Finance)	1998	BV Government private limited company	25,000 km	Autoriteit Consument Markt
SEPS	Slovakia (SK)	The Slovak Republic 100% (Ministry of Finance)	2002	Joint-stock company	3,100 km	Úrad pre reguláciu sieťových odvetví ÚRSO
APG	Austria (AT)	Verbund AG (51% owned by Republic of Austria)	2012	AG public limited liability company	7,000 km	E – Control Austria (ECA)
PSE	Poland (PL)	Poland 100% (State Treasury)	2004	Joint-stock company	16,133 km	Urząd Regulacji Energetyki

3.1. The Czech Republic – Profit and Cash-Flow of ČEPS (Česká Elektroenergetická Přenosová Soustava)

ČEPS is the sole transmission system operator in the Czech Republic. ČEPS was founded in 1998 and is fully owned by the state. The history of the ownership of ČEPS is shown in Table 2. ČEPS uses the international financial reporting standards (IFRS) for preparing its financial statements. The revenues of ČEPS are mainly generated from providing system and transmission services (including reservation of capacity), and from regulatory energy (in case of imbalance in the grid). Revenues from system services, revenues from the reservation of transmission equipment capacity and revenues from transmitted energy are regulated by

the Energy Regulatory Office (Energetický Regulační úřad ERÚ). ČEPS also sells free capacity to cross-border parties on daily, monthly and annual auctions of transmission rights.

Table 2. History of the ownership of ČEPS (annual report of ČEPS, 2023)

Years	Ownership of ČEPS (Česká elektroenergetická přenosová soustava)
1998–2003	100% ČEZ, a.s
2003–2004	34% ČEZ, a.s, 51 % OSINEK, a.s (owned by Ministry of Finance), 15% of Ministry of Labour and Social Affairs
2004–2009	34% Ministry of Finance, 51 % OSINEK, a.s (owned by Ministry of Finance), 15% of Ministry of Labour and Social Affairs
2009–2012	85 % Ministry of Industry and Trade, 15% of Ministry of Labour and Social Affairs
2012–2023	100% Ministry of Industry and Trade

The development of profit and cash-flow of ČEPS is shown in Table 3. ČEPS had a profit and positive operating cash-flow in all years, except 2022. ČEPS had a loss in 2022, which was reported to be compensated in the following years in form of the increased regulated fees for the customers.

Table 3. Development of the profit and cash-flow of ČEPS in CZK mil. (ČEPS, annual reports)

ČEPS data	2019	2020	2021	2022	2023
Revenues	15,059	14,867	17,740	24,251	22,747
Operating profit	3,770	2,906	4,136	(4,168)	8,195
Profit before tax	3,772	2,844	4,134	(4,122)	23,625
Net profit	3,063	2,235	3,306	(3,283)	19,628
Operating cash-flow	5,815	4,653	6,109	(1,529)	15,204
Investment cash-flow	(4,106)	(4,979)	(3,541)	(4,499)	(15,089)
Financial cash-flow	(2,146)	(1,040)	(780)	9,509	10,747
Paid out dividends	1,100	2,000	2,000	2,000	2,000

In 2023, there is a significant increase in profit, which is caused by a gain of 15,635 CZK mil, on a bargain purchase. ČEPS purchased the companies Gas Storage CZ, s.r.o (September 2023) and NET4GAS Holding, s.r.o (December 2023) and re-valued these companies to a fair value, thus increased their value in its consolidated financial statements and increased its profit. The financial cash-flow is positive in 2022 and 2023 due to increased borrowings and bank loans. ČEPS paid out dividends each year. Investments are ongoing and reported but not directly linked to the increase of renewable energy sources.

3.2. Slovakia – Profit and Cash-Flow of SEPS (Slovenská Elektrizačná Prenosová Sústava)

SEPS (Slovenská elektrizačná prenosová sústava) is the sole transmission system operator in the Slovak Republic. SEPS was founded in 2002 and is fully owned by the state, represented by the Ministry of Finances. The regulative authority of SEPS is RONI (Regulatory Office for Network Industries – Úrad pre reguláciu sieťových odvetví ÚRSO). SEPS uses the international financial reporting standards IFRS for preparing its financial statements. The development of profit and cash-flow of SEPS is shown in Table 4. SEPS had a profit in all years, except in 2020, which is related to the acquiring of OKTE (the short-term electricity market operator).

Table 4. Development of the profit and cash-flow of SEPS in thousands of EUR (SEPS, annual reports)

SEPS SK	2019	2020	2021	2022	2023
Revenues	461,582	377,884	510,727	454,563	881,618
Operating profit	95,550	(7,199)	203,931	92,477	66,668
Profit before tax	95,039	(7,808)	202,931	93,593	82,731
Net profit	69,302	(31,713)	168,603	70,018	62,062
Operating cash-flow	161,998	(1,052)	368,066	124,793	(3,717)
Investment cash-flow	(83,238)	(60,519)	(67,880)	(42,967)	(51,849)
Financial cash-flow	(47,420)	119,057	(61,083)	(5,677)	(79,782)
Paid out dividends	50,000	0	29,335	0	79,338

The annual report of SEPS (2023) states, that whether the SEPS Group makes a profit or a loss is influenced by the current electricity market and is also heavily dependent on how the RONI sets the prices of the Group's regulated activities according to the RONI Decree No 246/2023 Coll. Investment activities are also focusing on smart technologies at internal and cross-border level for the development of a modern energy infrastructure to integrate large amounts of electricity from renewable and distributed energy sources (SEPS, 2023).

3.3. Poland – Profit and Cash-Flow of PSE (Polskie Sieci Elektroenergetyczne)

PSE (Polskie Sieci Elektroenergetyczne) is the sole transmission system operator in Poland. PSE was founded in 2004 and is 100% owned by the State Treasury of Poland. Table 5 shows the development of the revenues, profit and the cash-flow of the company.

Table 5. Development of profit and cash-flow of PSE in polski złoty PLN (financial statements, PSE)

PL - PSE	2019	2020	2021	2022	2023
Revenues	8,966,229,522	9,522,394,255	17,536,117,157	25,473,210,913	26,406,192,204
Operating profit	874,952,325	1,443,688,410	1,456,715,287	800,896,756	2,394,781,911
Profit before tax	901,607,484	1,446,685,475	1,447,546,411	997,586,472	2,664,238,921
Net profit	729,360,861	1,170,183,108	1,180,055,937	797,006,129	2,168,889,169
Operating cash-flow	1,171,086,811	1,873,925,767	2,123,301,318	2,432,901,656	2,755,698,953
Investment cash-flow	(1,819,766,060)	(1,002,925,626)	(1,064,314,835)	(1,154,542,834)	(1,992,134,974)
Financial cash-flow	88,422,853	391,115,718	275,512,646	256,691,345	184,652,420
Paid out dividends ¹	0/127,6,29,137	0/185,440,782	0/120,497,332	0/258,616,162	0/53,667,344

¹ In the English summary (PSE, 2022a, 2022b), there are 0 paid out dividends to investors while in the original cash-flow statement (PSE, 2023) there are amounts (shown in Table 5) as dividends or other payments to the owners

PSE has its costs covered by transmission fees paid by the users of the transmission system, regulated by a tariff set by the overseeing authority (Urząd Regulacji Energetyki), similarly to the other countries. PSE has achieved profit and positive operating cash-flow in all years. However, PSE prepares its financial statements by using the Polish Accounting Act and the results may be not comparable with the other TSOs which use the international standards IFRS for financial reporting. PSE reports the increasing amount of renewable energy and the necessity of investments into a modern infrastructure (PSE, 2022b).

3.4. The Netherlands and Germany – Profit and Cash-Flow of TenneT Holding

TenneT is a Transmission System Operator (TSO) for the Netherlands and part of Germany, owned by the Dutch government (represented by the Ministry of Finance) managed by two operating segments TSO Netherlands and TSO Germany. TenneT owns and operates over 25,000 kilometres of high-voltage lines and cables (from which 13,965 km is in Germany). In Germany, TenneT transports the biggest share of green energy of Germany. The regulatory authorities for TenneT are Autoriteit Consument & Markt (ACM) in the Netherlands and Bundesnetzagentur (BNetzA) in Germany, which set the revenues TenneT is allowed to earn based on the rules set out in the legal framework. (Tennet, 2023). Table 6 shows the development of TenneT's profit and cash-flow in years 2019–2023. The profit in 2023 is achieved mainly by reporting the planned sale of the German part of the transmission system to the German state, reporting it as asset held for sale and as a discontinuing operation. TenneT announced the intended sale of the German part of the system to the German state in 2023. Table 6 shows what part of the items are for TenneT Holding as the whole and what part is the German part results (for years 2022–23). At the end of 2024 the sale reportedly stalled from both sides as in January 2, 2025 TenneT's official website reported that there is no final decision made by the Dutch government about the sale because the German side cannot deliver on the planned transaction due to budgetary challenges (TenneT, 2025). The investment cash-flow is minus in all years as TenneT invested around EUR 8 billion into the electricity grid expansion in 2023 (EUR 4.5 billion investments in 2022). The financial cash-flow is positive, mainly due to borrowings.

Table 6. Development of profit and cash-flow of TenneT Holding TSO B.V / TenneT Germany in mil EUR (financial statements, TenneT Holding)

TenneT Holding/ DE	2019	2020	2021	2022 ¹	2023 ¹
Revenues	4,422	5,025	5,524	8,299 / 6,380	2,297 / 7,001
Operating profit	1,077	1,356	(275)	(976) / (180)	172 / 1,252
Profit before tax	873	1,161	(475)	(1,233) / (414)	66 / 905
Net profit	623	837	(320)	(879) / (289)	711 / 644
Operating cash-flow	1,326	(96)	5,705	1,196 / 1,702	(1,654)/(2,236)
Investment cash-flow	(2,786)	(3,469)	(3,668)	(4,345)/(4,393)	(7,213)/(2,963)
Financial cash-flow	1,108	3,141	626	6,556/3,058	3,376/2,294
Paid out dividends	156	162	183	161	224

¹ Year 2022 shows the results of TenneT Holding including Tennet DE / Tennet DE, the year 2023 shows the results of TenneT Holding without TenneT DE / TenneT DE separately, due to the assumed discontinuing operation - planned sale of TenneT DE

The main revenues of TenneT are from providing connection and transmission services and from the maintenance of the energy balance. The revenues also include the operations of energy exchanges, which are revenues from auctioning the cross-border (electricity transmission interconnection) capacity. The TenneT tariffs exist of two components: the connection and transport tariffs. Parties connected to the national grid pay a connection fee to TenneT which covers the costs related to the installation, maintenance and replacement of a connection to the grid. Parties connected to the high

voltage grid pay a transmission fee to TenneT for each connection which covers the non-transmission related consumer tariff (for the costs of the administrative processing of metering data, billing costs) and transmission related consumer tariff (costs of the transmission of electricity, the unit price per kilowatt (kW)). TenneT Holding as a group generated profit, except the year 2022, but the TenneT TSO B.V (the Dutch part of TSO) reported losses for several years. Dividends were paid out 35% of the underlying profit (the profit calculated according to the German and Dutch national accounting legislation, not by the international standards IFRS). The Electricity Revenue Cap Act ("Strompreisbremsegesetz, StromPBG") was passed in 2022 for year 2023 by the German legislator, and it aimed to protect domestic end-consumers in 2023 from strongly increased electricity prices resulting from the turmoil on the energy markets in Europe following the war (Tennet Holding, 2023).

3.5. Germany – Profit and Cash-Flow of 50Hertz (50Hertz Transmission GmbH) and Eurogrid

As a transmission system operator (TSO), 50Hertz Transmission operates the extra-high voltage grid in northern and eastern Germany over a circuit length of approximately 10,500 km. 50Hertz is part of the international Elia Group. The shareholders of 50Hertz are the Belgian Elia Group (80%) and the KfW Bank Group (20%). The equity shares in 50Hertz are held via the German holding company Eurogrid. The development of profit and cash-flow of 50Hertz and Eurogrid is shown in Table 7.

50Hertz uses the German accounting legislation (German Commercial Code HGB) and the German Limited Liability Companies Act for preparing its financial statements, but they are also included in the consolidated financial statements of Eurogrid, which prepares their financial statements using the international standards IFRS for financial reporting. Even though both companies are reporting in EUR mil, the different accounting approach is visible in reporting the revenues. It can be seen that using the international standards IFRS (by Eurogrid) leads to much less reported revenues. 50Hertz does not report its net profit, as it is transferred to Eurogrid. The net profit of 50Hertz in Table 7 is the amount which is transferred to Eurogrid. 50Hertz also noted in their earlier annual reports, that renewable energy is a challenge for the grid (50Hertz, 2020).

Table 7. Development of profit and cash-flow of 50Hertz and Eurogrid in mil EUR (financial statements 50Hertz / financial statements Eurogrid)

50Hertz/ Eurogrid	2019	2020	2021	2022	2023
Operating revenues	10,718.9/1,360.2	11,095/1,454.8	7,902.2/1,716.9	6,9929/2,592.7	10,074.4/2,578.2
Operating profit	x/321.5	x/340.2	x/273	x/314.1	x/380.7
Profit before tax	x/256.2	x/277.6	x/238.2	x/341.4	x/320.9
Net profit	275.1/177.6	293.2/192.7	247/165.4	272,6/220.5	296,8/236.1
Operating cash-flow	(151.3)/(211.3)	(708.7)/(796.3)	3,650.4/3,720.7	713/764.1	(1,794.7)/(1,823.1)
Investing cash-flow	(431.5)	(724.1)	(501)/(831.4)	(1,039.5)/1,123.3	/(1,580.6)
Financial cash-flow	(308.3)	1,249	667/(328,7)	440.2/870,3	/796.8
Paid out dividends	x/120	x/120	x/120	x/120	x/130

3.6. Austria – Profit and Cash-Flow of APG (Austrian Power Grid)

APG (Austrian Power Grid), one of the two transmission system operators in Austria, was established in 2012. The owner is Verbund AG (of which 51% is owned by the state). The regulative authority is E-Control Austria. The development of profit and cash-flow is shown in Table 8. APG prepares its financial statements by using the Austrian GAAP (Generally Accepted Accounting Principles) and the Austrian Commercial Code (Unternehmensgesetzbuch UGB).

Table 8. Development of profit and cash-flow of APG in thousands of EUR (financial statements of APG Austria)

APG data	2019	2020	2021	2022	2023
Operating revenues	729,942	695,803	1,082,279	1,876,366	1,953,986
Operating profit	43,802.1	70,232	121,833.5	145,097.6	73,863
Profit before tax	24,092.2	46,959.7	97,950.8	119,086.6	60,009.7
Net profit	18,798.7	35,526	73,922.7	92,945.3	47,863.5
Operating cash-flow	213,089.7	190,991.7	253,979.3	223,298.2	558,142
Investment cash-flow	(193,297.1)	(347,196)	(382,261.2)	(351,469.7)	(440,091.2)
Financial cash-flow	(19,022.1)	153,217.9	128,206.4	129,004.2	(117,682.1)
Paid out dividends	19,686.4	9,733.9	18,163.5	37,342.9	47,111.1

Revenues of APG had been increasing during the past years, the net profit and the operating cash-flow is positive in all years, also the company paid out dividends in all years. However, APG prepares its financial statements by using the Austrian GAAP, so the results may not be comparable with the performance of other TSOs which use the international standards IFRS for financial reporting. APG reported that the increase of the renewables generation requires expansion of the transmission grid as the wind-power comes mainly from eastern Austria (APG, 2023).

4. Discussion

TSOs are natural monopolies and are regulated by a regulatory authority. The regulatory authority in the Czech Republic is ERÚ (Energetický regulační úřad). The regulatory authorities of the other neighbouring TSOs are shown in Table 1. In the Czech Republic, for 2024, the total regulated component of the price for end customers (which is decided by ERÚ and part of which is the fee for the transmission operator ČEPS), was announced to be 39.2% of price of electricity for households and small businesses (at the low voltage level), 29% for large customers at the high voltage level and 21% at the very high voltage level (ERÚ, 2023).

The regulation of revenues by the regulatory authorities are reported by most of the monitored transmission system operators, either by calling it a revenue cap or tariff or price cap, the meaning is the same. The cap influences the revenues and thus the profit. The methodology of calculation of the cap may be different, that is why the EU Agency ACER oversees the methodology for harmonization and fairness (ACER, 2024). The higher grid expenses and project costs (investments) are usually reimbursed through future tariffs, which results in considerable higher grid tariffs in future years (TenneT, 2023).

The transmission system operators mentioned in the paper also reported the challenges related to the increased amount of renewable energy from diverse sources connecting into the electric grid. The new trend of clean energy (encouraged by the very forceful EU policies, regulations and directives) makes the TSOs to improve and expand their grid system to include the increased amounts of renewable energy, also to maintain its reliability, which requires considerable investments, which in the end are paid by the end customers. The investment cash-flows of all TSOs are negative, which means they are continuously investing and have enough sources for investing. The financial cash-flow of the TSOs are mainly related to the borrowings and bank loans and their repayment. In some cases, the total cash-flow is positive only because the borrowings and loans (reported in the financial cash-flow). The dividends paid out are also reported in the financial cash-flow. Significant differences in revenues and profit reporting can be caused by the different accounting standards used. The proof of it is the German company 50Hertz and the Dutch company TenneT. For example, 50Hertz reports by the German accounting rules and its mother company Eurogrid (which includes the 50Hertz results in its consolidated reporting) reports by using the international financial reporting standards IFRS. The difference can be seen in Table 7, where revenues reported by 50Hertz are higher than the revenues reported by Eurogrid. TenneT uses for reporting the IFRS, but also reports the underlying profit (which is the calculation of profit by national accounting standards) and the difference is shown in their annual report, where the revenues and profit are higher if they are calculated by the national accounting standards. The Austrian TSO (APG) and the Polish TSO (PSE) seem to have the most consistent positive results, but it should be considered that these companies report and publish their results based on their national accounting legal frame, not according to international financial reporting standards IFRS.

5. Conclusions

One of the regulated components of the electricity price paid by the customers is the fee for the transmission system operators. The aim of the paper was to investigate whether the selected TSOs achieved profit and positive cash-flow over the past years. The 6 TSOs, namely ČEPS (the sole TSO in the Czech Republic) and its interconnected cross-border neighbouring TSOs: TenneT (NL, Germany), 50Hertz (Germany), APG (Austria), SEPS (the sole TSO in Slovakia) and PSE (the sole TSO in Poland) are all regulated by a national authority, which regulate the revenues what these operators can charge to the end customers thus influencing their profit. As the internal electricity market regulations of EU are leaning towards clean energy and the resulting increase of renewable energies feeding into the grid poses a challenge, investments into the grid and modern infrastructure are necessary. The different base of financial reporting of the TSOs can make the comparison of the reported profit and cash-flows difficult.

Further research will focus on the more detailed analysis of the individual TSOs and investigate the more complex aspects of the basic facts what seem to be established by the paper. The annual reports for the year 2024 will give more information, especially regarding the planned sale of the German part of TenneT to the German state, and also the financial results of ČEPS for 2024 after acquiring Gas Storage and Net4Gas in December 2023.

Conflict of interest: none

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Appendix 1. Members of the European Network of Transmission System Operators for Electricity (ENTSO-E, 2024)

Country	Transmission System Operators (TSO)	Abbreviation of the TSO
Austria	Austrian Power Grid AG Vorarlberger Übertragungsnetz GmbH	APG VUEN
Albania	OST sh.a – Albanian Transmission System Operator	OST
Bosnia and Herzegovina	Independent System Operator in Bosnia and Herzegovina	NOSBiH
Belgium	Elia System Operator SA	Elia
Bulgaria	Electroenergien Sistemen Operator EAD (Електроенергиен системен оператор)	ESO
Switzerland	Swissgrid ag	Swissgrid
Cyprus	Cyprus Transmission System Operator	Cyprus TSO
Czech Republic	ČEPS a.s.	ČEPS
Germany	TransnetBW GmbH TenneT TSO GmbH Amprion GmbH 50Hertz Transmission GmbH	TransnetBW TenneT DE Amprion 50Hertz
Denmark	Energinet	Energinet.dk
Estonia	Elering AS	Elering AS
Spain	Red Eléctrica de España S.A.	REE
Finland	Fingrid Oyj	Fingrid
France	Réseau de Transport d'Electricité	RTE
Greece	Independent Power Transmission Operator S.A.	IPTO
Croatia	HOPS d.d.	HOPS
Hungary	MAVIR Magyar Villamosenergia-ipari Átviteli Rendszerirányító Zártkörűen Működő Részvénytársaság	MAVIR ZRt.
Ireland	EirGrid plc	EirGrid
Iceland	Landsnet hf	Landsnet
Italy	Terna - Rete Elettrica Nazionale SpA	Terna
Lithuania	Litgrid AB	Litgrid
Luxembourg	Creos Luxembourg S.A.	Creos Luxembourg
Latvia	AS Augstsprieguma tīkls	AST
Montenegro	Crnogorski elektroprenosni sistem AD	Crnogorski elektroprenosni sistem
Northern Ireland	System Operator for Northern Ireland Ltd	SONI
Netherlands	TenneT TSO B.V.	TenneT NL
Norway	Statnett SF	Statnett
Republic of North Macedonia	Transmission System Operator of the Republic of North Macedonia	MEPSO
Poland	Polskie Sieci Elektroenergetyczne S.A.	PSA
Portugal	Rede Eléctrica Nacional, S.A.	REN
Romania	C.N. Transelectrica S.A.	Transelectrica
Serbia	Akcionarsko društvo Elektromreža Srbije	EMS
Sweden	Svenska Kraftnät	SVENSKA KRAFTNÄT
Slovenia	ELES, d.o.o.	ELES
Slovak Republic	Slovenská elektrizačná prenosová sústava, a.s.	SEPS
Ukraine	National Power Company Ukrenergo	Ukrenergo

Distribution of the Financial Burden in the Population

Karolína MARKOVÁ* and Peter PAŽITNÝ

Prague University of Economics and Business, Prague, Czech Republic; xmark43@vse.cz;
peter.pazitny@vse.cz

* Corresponding author: xmark43@vse.cz

Abstract: This contribution focuses on health care financing and its fairness which is a current topic considering the demographic challenges the health systems across Europe will face. These systems are functioning thanks to solidarity principle and the aging of population will create pressure on health systems in the near future. Hence it is important to assess the financial burden the households face which can serve as a tool for policymakers. The aim of this paper is to determine the level of fairness of Slovak health care financing system and distribution of the financial burden in the population using progressivity measure (Kakwani index). Using the household survey data, we computed the progressivity indices for several financing channels and for the system as a whole. We found that the health financing in Slovakia is proportionate or slightly progressive indicating that the system is fair, and no income groups are significantly disadvantaged.

Keywords: health system; financial burden; progressivity

JEL Classification: H51; H75; I14

1. Introduction

The future stability and sustainability of health systems is a frequently discussed topic. The development of health systems will be influenced by social, technological or demographic changes that will occur in the near future or are already present. These are, for example, the aging of the population or technological progress (OECD, 2017; OSN, 2021).

Some of these changes will be accompanied by rising costs and expenses. Health policy makers may also discuss the state's financial burden in the future and its reducing. In this context, the issue of total public sector expenditure is relevant as well as the amount of expenditure faced by households and the distribution of this expenditure in the population.

Equity in health system financing studies the distribution of financial burden in the population. It is one of the important indicators used for evaluation of health system performance. In a progressive payment system, wealthier individuals pay a larger share of their ability to pay than the poorer ones. In a regressive system, the rich pay a smaller share of their income than the poor. Progressive financing of the health system is seen as more suitable as it burdens poor households relatively less while systems with prevalent regressive payments are seen as not just (Ataguba et al., 2018).

Equity in health care financing has been formed from research focusing on tax systems and studying to what extent the tax systems meet the objectives related to the redistribution of income and wealth in society. This idea was applied to health systems, equity in health care financing studies whether payments to the health system contribute to the redistribution of income. The distribution of financial burden in population can be examined using progressivity measures. These analyze the distribution of payments among socioeconomic groups (Ataguba et al., 2018; O'Donnell et al., 2008).

Research focused on high income countries at first (Wagstaff et al., 1992; Wagstaff et al., 1999). Then, low-income countries started to be studied too (Ataguba & McIntyre, 2018; Mills et al., 2012; Munge & Briggs, 2014). Nowadays, research focuses on both types of countries (Ataguba et al., 2020; Crivelli & Salari, 2014; Edmonds & Hajizadeh, 2019; Nubler et al., 2023; Quintal & Lopes, 2016; Quintal, 2019; Ridde et al., 2015). Some authors use health financing incidence analysis to evaluate the impact of adopted policies (Asante et al., 2023; Baji et al., 2012; Cheng et al., 2022). The distribution of financial burden in a particular population depends on the structure of the tax and health system in a given country.

The aim of this paper is to determine the level of fairness of Slovak health care financing system and distribution of the financial burden in the population using progressivity measure (Kakwani index).

2. Methodology

It is known from the academic literature (Wagstaff and Dorslaer, 1989; Wagstaff and Dorslaer 1992), that different financing channels have different impacts on the population. In principle, direct taxes are mostly progressive, while indirect taxes are regressive. Public health insurance is mostly proportional or slightly progressive while direct payments are highly regressive. Kakwani index can be used for the measurement of progressivity (De Maio, 2007). The Kakwani index measures the progressivity of payments through the concentration index (C) and Gini index (G). The values range from -2 (indicating strong regressivity) to +1 (indicating strong progressiveness). The Kakwani Index is the result of the difference between the concentration index and the Gini index (Kakwani, 1977). Formally the concentration index is "defined as twice the area between the concentration curve and the line of equality (45° curve)" (O'Donnell et al., 2008, p. 95). The concentration curve shows the relationship between the studied variable and cumulative percentage of the population (Kakwani, 1980). The concentration index can be calculated as a covariance of the investigated variable and a fractional order of household living standard expressed by income (O'Donnell et al., 2008). This can be calculated using the following formula

$$C = \frac{2}{\mu} cov(h, r), \quad (1)$$

where h is the studied variable and μ is its average. The fractional order is denoted by r , the calculation of fractional order is $r_i = i/N$. It is a ranking of individuals according to their income, $i = 1$ for the poorest subjects and $i = N$ for the richest (O'Donnell et al., 2008).

For the calculation of Gini index following formula was used:

$$G(x_1, \dots, x_n) = \frac{2 \sum_{i=1}^n ix_i}{n \sum_{i=1}^n xi} - 1 - \frac{1}{n}, \quad (2)$$

where n is the number of individuals (Genčev et al., 2018).

The values of the Kakwani index for individual financing channels of health system were calculated on the micro data of Slovak households for the year 2022. The micro data were obtained from the Slovak statistical office and are not publicly available. The survey included 4,991 households. The individual financing channels (studied variables) are:

- Out-of-pocket payments (OOP);
- value added tax (VAT);
- personal income tax (PIT);
- public health insurance (PHI).

The data was first sorted by net income from lowest to highest. In the case of VAT, it was first necessary to calculate the corresponding values of the reimbursement from household consumption data. Table 1 summarizes the rates used for individual groups of goods and services.

Table 1. VAT rates for individual goods and services (year 2022)

Goods or services	Rate
Food and nonalcoholic beverages	10 %
Alcoholic beverages, tobacco and narcotics (expenses for narcotics were zero)	20 %
Clothing and footwear	20 %
Housing, water, electricity, gas and other fuels	20 %
Furniture and furnishings, general household maintenance	20 %
Health	10 %
Transport	20 %
Post and telecommunications	20 %
Recreation and culture	10 %
Education	20 %
Restaurants	20 %
Hotels	10 %
Various goods and services (the categories prostitution, insurance and financial services not otherwise classified were excluded)	20 %

In the case of income tax, it was necessary to calculate its value because the microdata contains net annual income. The incomes were divided into two groups according to the respective rates of the Slovak tax system (19 % and 25 %). Gross annual income up to EUR 38,553 was taxed at a rate of 19 %, higher income at a rate of 25 %. First, the gross annual salary was calculated according to the formula: net annual salary / (1 - tax rate). Subsequently, the difference between the gross and net annual income was calculated, which is equal to the income tax.

Subsequently, the averages of all investigated quantities (OOP, VAT, PIT, PHI) and income of subjects were calculated. In the next step, the values of the concentration index and the Gini index were calculated according to the formulas (1) and (2). The resulting Kakwani index is the difference between these indices.

3. Results

Table 2 shows the results for each financing channel as well as for the whole system. The index for the whole system is a weighted sum of all the financing channels indices. The weights were derived from the state final account (MFSR, 2022).

Table 2. Kakwani indices for all financing channels in Slovakia in 2022

Financing channel	Concentration index	Gini index	Kakwani index	Resources in the channel ¹	Weight of the channel	Weighted Kakwani index
Out-of-pocket payments	0.10	0.29	- 0.19	1,537,732	17.3 %	- 0.033
Public health insurance	0.49	0.29	+ 0.20	4,688,063	52.8 %	+ 0.106
Private health insurance	0.42	0.29	+ 0.12	80,168	0.9 %	+ 0.001
Value added tax	0.18	0.29	- 0.11	2,579,897 (1,288,969 + 316,830 + 974,098)	29.0 %	- 0.032
Personal income tax ²	0.33	0.29	+ 0.04	0 ²	0.0 %	0.000
Together				8,885,692		+ 0.042

¹ In thousand EUR, based on Pažitný et al. (2024)

² Personal income tax is a shared tax, and the entire tax revenue is redistributed by the established mechanism between cities and municipalities and higher territorial units.

The results can be interpreted through the table 3 below adapted from Kubátová (1997).

Table 3. Evaluation of progressivity indices. Source: Kubátová, 1997

Value of the index (%)	Evaluation
Less than - 30	Very regressive
- 30 to - 15	Quite regressive
- 15 to - 5	Slightly regressive
- 5 to + 5	Proportionate
+ 5 to + 15	Slightly progressive
+ 15 to + 30	Quite progressive
+ 30 and more	Very progressive

Out-of-pocket payments are evaluated as quite regressive (- 0.19) with the weight on total financing being 17.3 %. The value added tax is a key part of the state budget and is slightly regressive (- 0.11). The share of this tax on health care financing is 29 %. The income tax is mainly proportional (0.04), but the personal income tax is a shared tax, and the entire tax revenue is redistributed by the established mechanism between cities and municipalities and higher territorial units, so the proceeds from this tax are not used in Slovakia to finance healthcare. Private health insurance is slightly progressive (0.12), but its share in health care financing is minimal (0.9 %), so its impact on overall progressiveness is minimal. Public health insurance is quite progressive (0.20) and by having a dominant share in health care financing (52.8 %), it has a fundamental impact on the overall progressivity of the health system.

4. Discussion

Overall, the Slovak health system is on the border between proportional and moderately progressive, with a score of 0.042. This means that the financial burden is distributed fairly, and no income group is favored or disadvantaged compared to another. A key role in this is played by the progressivity of public health insurance combined with its dominant share in health care financing. At the same time, there is still room for an increase in the total share of direct payments to the population in the overall financing of healthcare.

Based on empirical data from European and other countries, it can be stated that regressive payments are mostly OOP and indirect taxes. Income tax, on the other hand, is often progressive. In the case of all channels, however, the design of the given system is important. These characteristics have a major influence on the resulting level of equity. Often it also depends on the data used. In the case of Slovakia, the value added tax is regressive as this tax is included in the goods and services. Out-of-pocket payments are regressive because the direct payment is not linked to income. The main source of financing, the public health insurance, is progressive. The reason is the so-called deductible for health insurance for low-income workers. The principle is that this deductible reduces the base for calculation of health insurance payment. This lowers the financial burden on low-income individuals and thus increases the progressivity of this channel. Private health insurance is progressive too although its impact on overall equity is small, mainly people with high incomes use private insurance as the public health insurance has a wide coverage.

The presented model can be used by health policy makers as a decision-making tool helping with introducing an effective health financing policy. Changes in health financing policies can be evaluated in terms of equity and distribution of financial burden in population. Regarding health financing policy the results suggest that additional regressive payments can be adopted. Such interventions might be needed due to the future challenges the system will face. However, new developments in the tax system must be considered. In 2025 such intervention was adopted in an existing channel, the rate of value added tax increased from 20 % to 23 %. This change will bring more resources to the system, but it will also increase the regressivity of the system. Equity should be thus re-evaluated.

Limitations of the paper include for example the absence of consumption taxes in analysis which burden consumers too. However, there is currently no data which could be used for the computation of Kakwani index for this tax. Another limitation might lie in the data as the respondents could be insincere.

Next research can be focused on identifying new financing channels or adjusting the current ones with respect to the equity of the system.

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The Use of AHP in Business: Systematic Review

Martin MATĚJČEK* and Petra MAREŠOVÁ

University of Hradec Králové, Hradec Králové, Czech Republic; martin.matejcek@uhk.cz;
petra.maresova@uhk.cz

* Corresponding author: martin.matejcek@uhk.cz

Abstract: Decision-making processes in companies are complex and require efficient tools for processing information. This study focuses on the application of the Analytic Hierarchy Process (AHP) and its variants, including fuzzy AHP, in business and management. The main aim was to explore the use of these methods across various sectors and to identify trends and challenges associated with their implementation. For this purpose, a systematic review was conducted using database searches and strict filtering criteria to select relevant studies. The results indicate that AHP and other multi-criteria decision-making methods (such as ANP, TOPSIS, VIKOR, MOORA, MAUT, MAVT, SAW, and PROMETHEE) are applied in the aviation industry, supply chain management, energy, postal services, and the automotive industry. The study confirms that AHP offers a structured approach to quantifying and comparing criteria; however, its application is context-specific. Further research is necessary to maximize the potential of AHP and contribute to the development of effective decision-making tools.

Keywords: MCDM; AHP; analytic hierarchy process; business; management

JEL Classification: C44; M11; D81

1. Introduction

In business and management, decision-making often involves balancing multiple conflicting factors, making Multi-Criteria Decision Making (MCDM) methods essential (Ho, 2008). MCDM focuses on developing and applying methods to evaluate complex problems involving multiple criteria, integrating various perspectives and interests.

Among MCDM methods, the Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty, is widely used (Saaty, 1987). AHP structures decision problems hierarchically, enabling systematic comparisons of criteria and alternatives. Saaty's works provide a comprehensive methodology for calculating weight assignments in decision hierarchies. Fuzzy AHP, incorporating fuzzy logic, enhances handling uncertainty and subjectivity in decision-making (Kahraman et al., 2003).

AHP has broad business applications, including strategic planning, supplier selection, risk management, and resource allocation (Saaty & Vargas, 2012). It has been used for example for equipment selection in manufacturing (Yurdakul, 2004), and financial performance assessment (Monga et al., 2021).

This article focuses on a PRISMA systematic literature review concerning the use of AHP in business and management. The aim is to map how AHP, within the broader spectrum

of MCDM methods, contributes to the effective resolution of complex decision-making tasks in a business context.

The structure of the article is as follows: Following this introduction, the article outlines the methodology, describing the process of systematically collecting and analyzing the literature. The results section discusses the findings from the bibliographic analysis, emphasizing key trends and insights. The discussion section further examines the impact of these findings on business practice and theory. In conclusion, the main findings are summarized, and future research directions are indicated—specifically regarding the use of the AHP method in the medical device industry.

2. Methodology

For the purposes of the systematic review, a detailed search process was carried out in the Web of Science database during the first phase of the project. This process was conducted on October 13, 2023, and included specific search parameters aimed at identifying relevant literature on the Analytic Hierarchy Process (AHP) and its applications in business and management. The detailed search criteria were as follows:

- Search date: The research was conducted on October 13, 2023, ensuring the timeliness and relevance of the collected data.
- Search query: A specific query was formulated to focus on a combination of keywords and phrases. The search query “Topic: (‘ahp’ OR ‘analytic hierarchy process’) AND (‘company’ OR ‘business’) AND ‘management’” was chosen to target literature concerning AHP in the context of business and management.
- Publication years: The search was limited to documents published between 2019 and 2023, allowing the focus to be on the most recent research and developments in the field.
- Document types: Only scholarly articles (“article”) were selected to ensure a high level of academic rigor and relevance for scholarly research.
- Categories: Four main categories were chosen - “Engineering,” “Business Economics,” “Science Technology Other Topics,” and “Operations Research Management Science.” This multidisciplinary approach was selected to obtain a wide range of perspectives and applications of AHP.

As a result of this search process, a total of 472 articles from the Web of Science Core Collection were identified that met the set criteria.

In addition to the search in the Web of Science database, a supplementary search was also conducted in the ScienceDirect database. This step was necessary to ensure the comprehensiveness of the PRISMA systematic review and to include a broader spectrum of relevant literature. The search in ScienceDirect was carried out with the following specifications:

- Search date: As with the previous database, the search was conducted on October 13, 2023, ensuring the timeliness of the information obtained.

- Search query: The query was set to focus on the titles, abstracts, and keywords of articles. The formulation "Title, abstract, keywords: ('ahp' OR 'analytic hierarchy process') AND ('company' OR 'business') AND 'management'" was intended to identify publications that directly address the Analytic Hierarchy Process (AHP) in the context of business and management.
- Publication years: Limiting the search to the period from 2019 to 2023 ensured a focus on the latest available studies and research.
- Article type: Only research articles ("Research articles") were selected, which contributed to ensuring scientific rigor and relevance to the topic.
- Fields: The search included articles from the fields of "Engineering," "Decision Sciences," "Business, Management and Accounting," and "Economics, Econometrics and Finance." This multidisciplinary approach enabled the acquisition of a wide range of perspectives and approaches to AHP.

Thanks to this search process, a total of 48 publications meeting the set criteria were identified in the ScienceDirect database. These publications were subsequently included in further analysis and evaluation as part of the systematic review, providing a more comprehensive view of the current state and applications of AHP in business and management.

In the next phase of the research, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) procedure was used to filter and select relevant studies. Figure 1 visualizes the entire PRISMA process, detailing the step-by-step selection of articles. PRISMA is a standardized method for conducting systematic reviews and meta-analyses, with the primary goal of increasing the transparency and reproducibility of research (Moher et al., 2009).

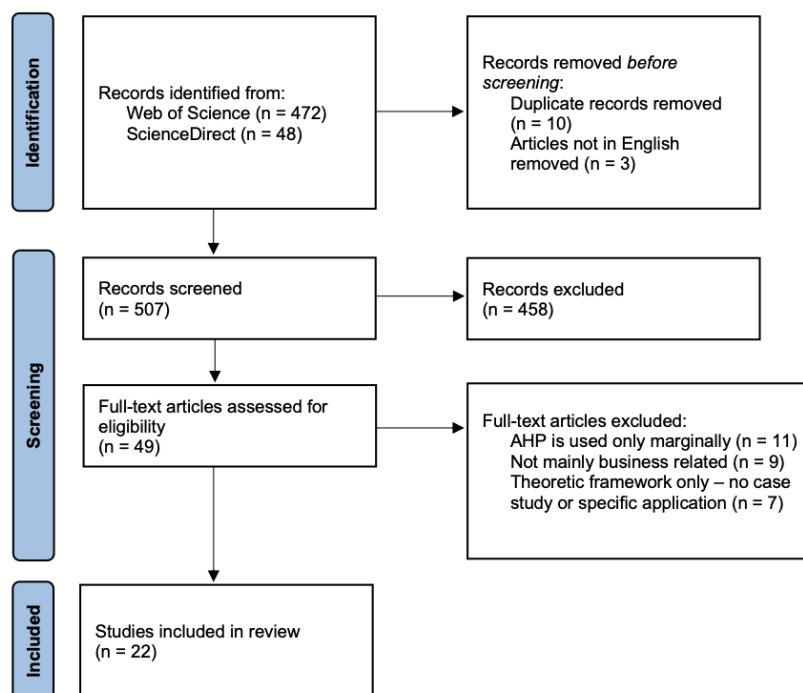


Figure 1. PRISMA flow diagram (Moher et al., 2009)

From the initial set of 520 publications (472 from Web of Science and 48 from ScienceDirect), 10 duplicates and 3 articles that were not in English were first removed. After these adjustments, a total of 507 articles were prepared for screening.

These articles were then filtered based on specific criteria:

- Use of the AHP or fuzzy AHP method: Studies had to primarily utilize the Analytic Hierarchy Process (AHP) or its fuzzy AHP variant. They could also include other multi-criteria decision-making (MCDM) methods, but the inclusion of AHP or fuzzy AHP was considered essential.
- Occurrence in a business or management context: Articles had to be directly related to the field of business or enterprise management.

After the first screening phase, which involved reading titles and keywords, 355 articles were removed. In the next phase, which involved reading abstracts, an additional 103 articles were excluded. Finally, after reading the full texts, another 27 articles were eliminated due to reasons such as marginal use of the AHP method (11 publications), insufficient focus on the business environment or enterprise management (9 publications), or because the publication was merely a theoretical framework without a specific case study or practical application (7 publications).

Thus, from the initial 520 publications, 22 articles were selected for the final review as they met all the established criteria and were considered relevant for the systematic review.

3. Results

The search in the Web of Science Core Collection resulted in a total of 472 articles. The trend over the years is reflected in Figure 2, which displays the number of works based on keywords related to the Analytic Hierarchy Process, business, and management.

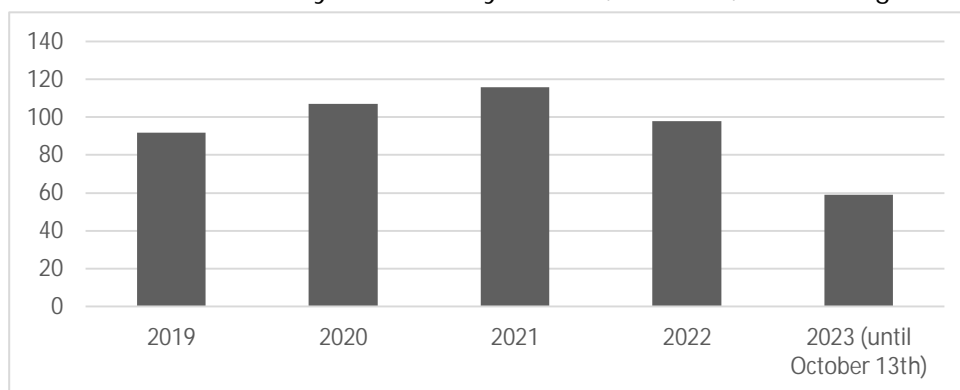


Figure 2. Publication counts in the WOS (Web of Science) database based on keyword searches ("ahp" OR "analytic hierarchy process") AND ("company" OR "business") AND "management"

The highest number of publications was identified in 2021 (116 publications), while the fewest works have been recorded so far in 2023 (59 publications), which can be attributed to the search date – October 13, 2023.

When looking at Figure 3, the overall number of citations for the period from 2019 to 2023 is evident. Citations increased from 80 in 2019 to 509 the following year, reaching a peak of 1901 citations in 2022. Although there was a decline to 1528 in 2023, it is important to note

the limitation of the data up to October of that year. This citation trend demonstrates the growing impact and importance of the Analytic Hierarchy Process in management and business research.

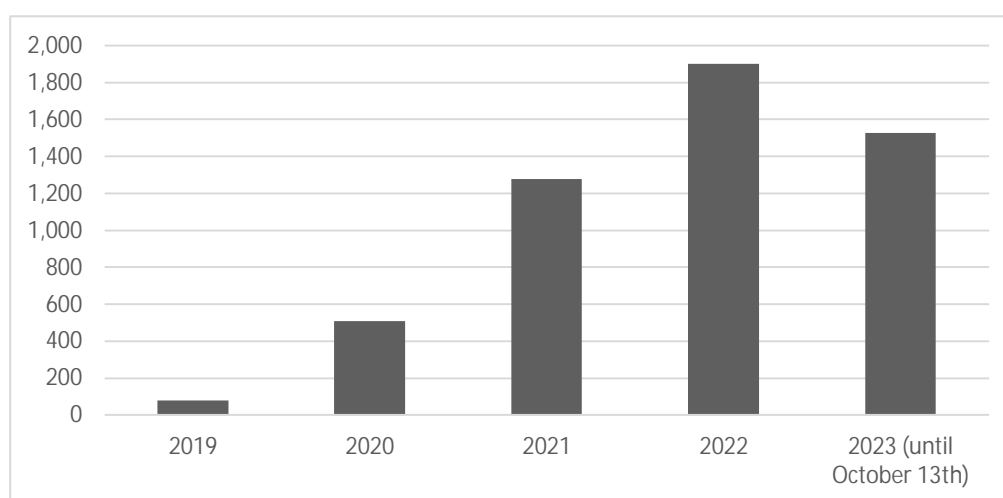


Figure 3. Number of citations found using the keywords ("ahp" OR "analytic hierarchy process") AND ("company" OR "business") AND "management" from 2019 to 2023 in Web of Science

In conclusion, the citation metrics from the collected data show that the mentioned articles have been cited a total of 5,313 times, with an average of 11.26 citations per publication, revealing a sustained academic interest in the topic. Over 4,620 citing articles illustrate the extensive integration of these findings into the broader research discourse. After subtracting self-citations, 4,525 citing works remain, emphasizing the influence and recognition of the contribution of the studied subject. An H-index of 35 further confirms the significant and enduring scientific contribution of these publications.

After an additional search in the ScienceDirect database, a careful filtering of publications according to predefined criteria was carried out. These criteria, described in detail in the Methodology chapter, included topic relevance, methodological quality, and the scope of the study within the field of AHP applied in business and management. Finally, 22 studies were selected for detailed analysis, which are described in Table 1. These studies provide a valuable overview of the use of AHP in various areas of business and management, revealing current trends and applications of this methodology. This table briefly summarizes the key aspects of each study, such as authors, titles, specific fields of application, case study details, problem-solving approaches, results, limitations, and key comments in the context of AHP.

The analysis of selected studies highlights the diverse applications of the Analytic Hierarchy Process (AHP) in business and management across industries such as aerospace, supply chain management, energy, postal services, and automotive. AHP is used for tasks ranging from optimizing manufacturing to selecting auditors and managing project portfolios. Most studies emphasize its role in quantitatively evaluating and prioritizing decision criteria, crucial for performance improvement and strategic planning.

Table 1. Chosen studies

Author (year)	Title	Area	Case study	Problem addressed	Results/Findings	Limitations	Comment
(Lin & Chen, 2019)	3D Printing Technologies for Enhancing the Sustainability of an Aircraft Manufacturing or MRO Company - a multi-expert partial consensus-FAHP analysis	Aircraft manufacturing and maintenance, repair, and overhaul (MRO)	Yes – 3 experts and an aircraft manufacturing context	Determining the priority of critical factors to improve the sustainability of companies in the aviation industry that apply 3D printing technologies	Five key factors for sustainability in the aviation industry were identified: cost-effectiveness, demand coverage, 3D printing capabilities, research and development, and local market growth. These findings differ from those obtained using other FAHP methods.	The study involved a limited number of participants (three experts) and was conducted in a specific aviation context, which may restrict the generalizability of the results to other sectors.	he PC-FAHP method proved effective in analyzing fuzzy expert evaluations to determine key sustainability factors in the aviation industry when full consensus among experts was lacking.
(Roy et al., 2020)	A Framework for Sustainable Supplier Selection with Transportation Criteria	Supply chain management, with a special focus on sustainable supplier selection	Yes – a textile company in Bangladesh	Addressing the problem of sustainable supplier selection in the supply chain	The integration of fuzzy logic and the PROMETHEE methodology significantly improves supplier selection decision-making by considering sustainability and reducing subjectivity.	The study is limited to the apparel industry, does not include quantitative values for some factors, and does not account for interconnections between criteria, which limits its applicability.	Although AHP is useful for weighting criteria, its integration with PROMETHEE offers a more comprehensive and coherent approach to supplier selection.
(Krishnan et al., 2019)	A Hierarchical Model to Enhance Financial and Strategic Performance of an Oil and Gas Company in Malaysia	Management and strategic planning in a company operating in the energy sector	Yes – the entire article is a case study of an oil and gas company in Malaysia	Identification and prioritization of key competencies within an oil and gas company	The research resulted in a hierarchical model that prioritizes key competencies essential for achieving competitive advantage, financial gain, and strategic performance in the oil and gas sector.	The study faced limitations in respondent distribution (58% from downstream and 42% from upstream) and a lack of participants from finance and human resources departments.	The application of AHP represents an innovative approach to evaluating key competencies, providing a quantitative basis for strategic decision-

							making in the oil and gas industry.
(Lazarević et al., 2020)	A Model for Business Performance Improvement: a Case of the Postal Company	Management and business performance improvement	Yes – a postal company	The problem of optimizing the business performance of a postal company	The study identified inefficient resource management, insufficient communication, and a lack of innovation as the main issues. The implementation of the proposed strategies led to a significant improvement in the company's performance.	The data were limited to one postal company, which may affect the generalizability of the results. A lack of comparative data and regional differences might also skew the interpretation of findings.	The study offers valuable insights into logistics optimization, although incorporating AHP could provide a deeper analysis of priorities and a better decision-making framework for strategic planning in the postal sector.
(Beskese et al., 2019)	A Model Proposal for ERP System Selection in Automotive Industry	Automotive industry	Yes – a large multinational automotive company	Selecting the most suitable ERP software for specific needs within the automotive industry using fuzzy logic methods	It was found that ERP System A outperforms others due to its flexibility and process integration, while ERP System B excelled in financial evaluation and user-friendliness.	The study's sample was small and focused on only two ERP systems, which may affect the generalizability and objectivity of the results.	-making process and offering valuable insights into integrating quantitative methods into practice.
(Rodrigues et al., 2022)	A Supplier Selection Decision Model Using Multi-criteria Decision Analysis in a Small Manufacturing Company	Supply chain management in a manufacturing company	Yes – a company manufacturing automotive parts	Decision-making for the selection of suppliers for capital spare parts in the context of Industry 4.0 and digitalization	The results highlighted the importance of evaluating decision-makers and their influence on the outputs of both AHP and ANP methods in the supplier selection process.	The study encountered difficulties convincing managers to adopt new mathematical approaches and struggled with analyzing the consistency of their evaluations.	The publication provides a valuable comparison of AHP and ANP methods in practice, emphasizing their relevance and the need for adaptation in a dynamic industrial environment.
(Manik, 2023)	Addressing the Supplier Selection Problem by Using	Supply chain management in the	Yes – ACI Pharma, a major	The problem of selecting suppliers for	The study identified Spark Printers as the best supplier for ACI Pharma	The study is limited to the use of AHP without methodological	The publication provides a practical example of AHP

	the Analytical Hierarchy Process	pharmaceutical industry	conglomerate in Bangladesh	printing materials for ACI Pharma	with the highest score of 0.968, followed by Marvelous Printers Limited and Lutfur Enterprise.	justification and does not include social or environmental sustainability aspects in supplier selection.	application in the industry but emphasizes the need for further research to compare with other MCDM methods for a more comprehensive analysis.
(Canco et al., 2021)	AHP, a Reliable Method for Quality Decision Making: A Case Study in Business	Business management	Yes – a company from Albania (S. & Co)	Implementation of the Analytical Hierarchy Process (AHP) to improve managerial decision-making	The study showed that AHP has the potential to enhance decision quality in a corporate environment by enabling rational and efficient resolution of complex business problems.	The application of AHP was limited to one company and one area, and the study relied on the perceptions of managers and consumers for criteria identification, which may be subjective.	The study emphasizes the importance of AHP for multi-criteria decision-making, highlighting its effectiveness from both managerial and consumer perspectives, and recommends its broader use to improve competitive performance.
(Xue et al., 2019)	An Evaluation Framework for the Planning of Electric Car-Sharing Systems: A Combination Model of AHP-CBA-VD	Planning of electric car-sharing systems (ECSS)	Yes – EVCARD, the most influential electric car-sharing operator in China	Optimization of planning for an electric car-sharing system in the context of Chinese urban areas	The results indicate that the management of vehicle availability and their relocation have the greatest influence on ECSS planning in China.	The study's limitations include a specific focus on EVCARD and limited applicability of the results to different regions or other car-sharing companies.	In the context of AHP, the publication provides an innovative and comprehensive framework for evaluating ECSS planning.
(İç et al., 2022)	An Integrated AHP-Modified VIKOR Model for Financial Performance Modeling in Retail	Financial performance evaluation of companies in the retail and	Yes – Turkish retail and wholesale sector	Developing a new model for measuring financial performance that combines AHP	The study found that large companies with a stronger capital structure are more resilient to market fluctuations; the AHP-VIKOR model provides	Limitations include the use of a simple weighting method, results applicable only to six Turkish companies, and the	The article innovatively combines AHP with a modified VIKOR method for evaluating financial performance, emphasizing the

	and Wholesale Trade Companies	wholesale trade sector		with a modified VIKOR method	effective tools for financial performance measurement in the sector.	exclusion of potential interactions between financial indicators.	flexibility and importance of criteria weighting in AHP.
(Martino Neto et al., 2023)	Compatibility and Correlation of Multi-attribute Decision Making: a Case of Industrial Relocation	Operations research – industrial relocation	Yes – a French industrial group	Relocation of a plant located in São Paulo, Brazil	The use of AHP, MAUT, MAVT, and TOPSIS clearly recommended keeping the industrial plant in São Paulo due to the highest overall scores across all criteria.	he study is limited to a single industrial facility and does not consider political or social aspects, which may affect the generalizability of its conclusions.	The publication adeptly applies AHP and other MADM methods, demonstrating a nuanced approach to industrial relocation decision-making that goes beyond mere cost analysis.
(Silva et al., 2019)	Criticality Evaluation of Spare Parts Using the Analytic Hierarchy Process with Ratings	Spare parts management	Yes – a capital-intensive company based in South Fluminense	The challenge of effectively managing spare parts inventory with high holding costs and low turnover	Ten low-turnover spare parts were analyzed and prioritized using AHP and VED criteria, enabling the establishment of differentiated inventory policies.	The study is confined to low-turnover spare parts in one organization, which may limit the generalizability of the results to other scenarios or industries.	The publication effectively utilizes AHP to address spare parts inventory policies, providing a valuable framework for prioritizing inventory based on part criticality.
(Ansari et al., 2022)	Decision Support System for Analyzing Key Performance Indicators in Construction Projects Management	Construction project management	No – however, it is a specific application in the construction sector in Iran, supported by a survey	Management of claims and their impact on project performance	The study identified delays as the primary cause of claims—with the greatest impact on key performance indicators—followed by project changes and factors such as work acceleration and ambiguities in contracts.	The study may be limited by its regional focus on Iran and might not encompass all factors influencing claims in various construction environments.	The publication effectively utilizes AHP and TOPSIS to structure and quantify the impact of claims, enabling targeted improvements in construction project performance.

(Abdelmaguid & Elrashidy, 2019)	Halting Decisions for Gas Pipeline Construction Projects Using AHP: a Case Study	Gas pipeline construction and management	Yes – a company involved in gas pipeline construction in Egypt	Making decisions on whether to continue or halt a group of ongoing gas pipeline construction projects facing unpredictable risks	AHP effectively identified the priority decision to halt one project while allowing the other two to continue, emphasizing the importance of political and economic stability for pipeline projects.	The main limitation lies in AHP's restricted ability to handle a large number of decision alternatives, which complicates its application when many projects are involved.	This publication demonstrates AHP as a robust tool for complex decision-making in construction, despite its limitations with numerous alternatives.
(Chiarini, 2019)	Choosing Action Plans for Strategic Manufacturing Objectives Using AHP Analysis of the Path and Pitfalls Encountered - an Exploratory Case Study	Manufacturing strategy management and decision-making processes	Yes – a medium-sized Italian manufacturing company	Selection among alternative action plans for the implementation of strategic manufacturing objectives	The results showed that AHP refines the decision-making process through quantitative evaluation of alternatives, aiding managers in making more objective choices, though organizational obstacles and pitfalls were encountered.	The study is based on a single case in one manufacturing company; its conclusions should be validated through further research in diverse organizational contexts.	The publication broadens the understanding of AHP's use in strategic manufacturing decision-making, highlighting both its potential and the challenges of its application in a corporate setting.
(Umaporn Vimonkittipong, 2022)	Location Selection Model for a Dental Clinic in a Low to Medium Rent Commercial Building	Dental services	Yes – conducted in Thailand (Bangkok) with dental clinics and experts	Location selection for a dental clinic using the Analytical Hierarchy Process	The research identified transportation, community factors, and parking as key criteria for selecting the location of dental clinics in Bangkok with rents up to \$750. Proximity to main roads and residential areas was also deemed important.	The study is geographically limited to a specific locale and confined to the dental industry.	The AHP method provided a quantitative evaluation of priorities, enabling an objective comparison of criteria for selecting a dental clinic location, thereby demonstrating its effectiveness in business decision-making.
(Barkaoui et al., 2023)	Multi-Criteria Decision Making	Medical device development	Yes – development of a 3D	Presentation of a multi-criteria decision-making	The DPMA approach, which combines AHP, GDM, and SAW methods,	The study faces challenges in cases of borderline GO/NO GO	The study effectively integrates AHP into the DPMA framework to

	for Medical Device Development		printed femoral prosthesis	process called Define, Prioritize, Measure, and Aggregate (DPMA)	effectively aided decision-making in the development of a 3D printed femoral prosthesis, offering managers key insights and identifying areas for improvement.	results, may be influenced by experts' subjective opinions, and is specific to certain types of medical devices.	optimize decision-making in medical device development, providing a structured method for weighting criteria and enhancing transparency in complex multi-criteria situations.
(Islam & Periaiah, 2023)	Overcoming the Pitfalls in Employee Performance evaluation: An Application of Ratings Mode of the Analytic Hierarchy Process	Employee performance evaluation	Yes – CLSB company in Kuala Lumpur, Malaysia	Evaluating employee performance using the Analytical Hierarchy Process	In CLSB, five key criteria were identified for employee performance evaluation: service, quality, finance, timing, and teamwork. The most important sub-criteria were harmonious work, skills, and punctuality.	The tool was developed exclusively for CLSB; necessary adjustments are required before applying it to other organizations.	This publication effectively demonstrates the application of AHP in employee performance evaluation, emphasizing objectivity and overcoming subjectivity inherent in traditional methods.
(Szilágyi et al., 2020)	Project Ranking in Petroleum Exploration	Oil and gas industry	Yes – petroleum exploration	A method for evaluating and selecting projects in oil and gas exploration, particularly within the context of limited resources and strategic organizational goals	The Project Portfolio Index (PPI) improves the evaluation and selection of oil projects by combining financial and non-financial factors, thereby maximizing portfolio value within the investment budget.	The approach is limited to oil and gas exploration; PPI is designed as a one-off method without long-term analysis and requires careful consideration of subjective decisions in AHP.	The article applies AHP for evaluating oil projects by incorporating both financial and non-financial factors and utilizes AHP in conjunction with PPI for a robust evaluation.

(Muniz et al., 2021)	Spare Parts Inventory Management: a New Hybrid Approach	Spare parts inventory management	Yes – an iron mining company in Brazil	Development of a new approach to reduce the value of spare parts inventory in the early stages of the mining industry	The article describes a new multi-objective optimization approach with multi-criteria evaluation for managing spare parts inventory, which resulted in a 20.2% increase in criticality and a 16.6% increase in the number of stored items.	The proposed approach was applied only to a mining company in Brazil; future research should examine the suitability of the criticality criteria in other companies or regions.	The article effectively uses AHP to quantify the relevance of criteria in spare parts management, enhancing the precision of the decision-making process and allowing for a deeper analysis of inventory criticality in the mining industry.
(Kuvat & Kılıç, 2020)	The Evaluation of the Criteria for the Selection and Change of the Independent Audit Firm Using the AHP Method	Accounting and audit	Yes – a food sector entity in Turkey	Identification and prioritization of key criteria for selecting and changing independent audit firms for businesses	The results indicated that the most important factors for selecting an audit firm are the provision of international services and the professional quality of the firm. In cases of changing audit firms, the rotation of the independent audit body is a key criterion.	The study was conducted in a single company within Turkey's food sector, limiting its general applicability and comparability with other sectors.	The article uses AHP to evaluate criteria for selecting an audit firm, providing a robust and systematic analysis of the decision factors in auditing.
(Mohammed, 2023)	The Optimal Project Selection in Portfolio Management Using Fuzzy Multi-criteria Decision-making Methodology	Portfolio management	Yes – Iraqi oil companies	Using MCDM to set priorities and select projects in a corporate portfolio	The research found that Project 3 is optimal for portfolio management using the fuzzy AHP method for weighting criteria and fuzzy TOPSIS for evaluation, assisting decision-makers—albeit requiring a comprehensive understanding of the context.	This approach may be limited by its reliance on expert evaluations for setting criteria weights and the recording of linguistic preferences, which can introduce subjective errors and inaccuracies.	The fuzzy AHP method allows for a systematic determination of criteria weights for multi-criteria project evaluation but depends on expert assessments and requires careful management of subjective linguistic preferences.

However, studies often have limitations, being confined to specific companies or industries. For example, Lin and Chen (2019) studied 3D printing in aerospace with only three experts, while Roy et al. (2020) focused on sustainable supplier selection in Bangladesh's textile industry. Rodrigues et al. (2022) highlighted the challenge of persuading managers to adopt mathematical approaches in supplier selection.

Many studies stress the need for further research to validate findings. For instance, Islam and Periaiah (2023) emphasized adapting AHP for employee performance evaluation in different organizations. Other studies, such as Lazarević et al. (2020) on postal logistics and Muniz et al. (2021) on spare parts management, demonstrated AHP's effectiveness but noted the need for deeper customization to maximize its impact.

The following Table 2 provides a structured overview of the MCDM (Multi-Criteria Decision Making) methods used in the respective studies. At first glance, it is evident that the studies included in this analysis were selected based on a fundamental criterion: the primary use of the Analytic Hierarchy Process (AHP) or its variant, fuzzy AHP. This key selection criterion highlights the centrality of AHP in the examined studies.

In addition to AHP/fuzzy AHP, some cases also employ other methods, such as ANP (Analytic Network Process), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), Fuzzy TOPSIS, VIKOR (ViseKriterijumska Optimizacija I Kompromisno Resenje), MOORA (Multi-Objective Optimization on the Basis of Ratio Analysis), MAUT (Multi-Attribute Utility Theory), MAVT (Multi-Attribute Value Theory), SAW (Simple Additive Weighting), and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation).

The diversity of applied methods suggests that researchers seek various approaches to solving complex decision-making problems in business. While AHP and its variants, such as Fuzzy AHP, offer a structured framework for quantifying and comparing different criteria, other methods like TOPSIS or VIKOR provide alternative approaches for evaluating and selecting the best options within a given problem context. This methodological diversity underscores the complexity of decision-making processes in business and the need to tailor methods to specific contexts and research requirements.

The choice of a particular method often reflects the nature of the problem under study and specific analytical requirements. For example, while AHP is excellent for hierarchical decision-making, TOPSIS and Fuzzy TOPSIS are more suitable for comparing alternatives based on their proximity to an ideal solution. The use of combined or hybrid approaches, such as AHP with VIKOR, indicates an effort to achieve more robust and multidimensional analyses, which is crucial for managing complexity and uncertainty in business environments.

Overall, the table of applied methods reveals that the use of MCDM methods in business is dynamic and multidisciplinary, emphasizing the potential for combining different approaches to achieve comprehensive and practical solutions.

Table 2. Used MCDM methods

Author (year)	AHP (Analytic Hierarchy Process)	ANP (Analytic Network Process)	Fuzzy AHP (Fuzzy Analytic Hierarchy Process)	TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)	Fuzzy TOPSIS (Fuzzy Technique for Order of Preference by Similarity to Ideal Solution)	VIKOR (ViseKriteri- jumska Optimizacija I Kompromi- sno Resenje)	MOORA (Multi- Objective Optimizatio n on the basis of Ratio Analysis)	MAUT (Multi- Attribute Utility Theory)	MAVT (Multi- Attribute Value Theory)	SAW (Simple Additive Weighting)	PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation)
(Lin & Chen, 2019)			x								
(Roy et al., 2020)			x								x
(Krishnan et al., 2019)	x	x									
(Lazarević et al., 2020)	x										
(Beskese et al., 2019)			x		x						
(Rodrigues et al., 2022)	x	x									
(Manik, 2023)	x										
(Canco et al., 2021)	x										
(Xue et al., 2019)	x										
(İç et al., 2022)	x			x		x	x				
(Martino Neto et al., 2023)	x			x				x	x		
(Silva et al., 2019)	x										
(Ansari et al., 2022)	x			x							
(Abdelmaguid & Elrashidy, 2019)	x										
(Chiarini, 2019)	x										
(Umaporn Vimontipong, 2022)	x										
(Barkaoui et al., 2023)	x									x	
(Islam & Periaiah, 2023)	x										
(Szilágyi et al., 2020)	x										
(Muniz et al., 2021)	x										
(Kuvat & Kılıç, 2020)	x										
(Mohammed, 2023)			x		x						

4. Discussion and Conclusions

The analysis of selected studies reveals a broad range of applications of the Analytic Hierarchy Process (AHP) across various business and management sectors, from aerospace to energy and the automotive industry. Most studies highlight AHP's key role in the quantitative evaluation and prioritization of criteria, essential for improving performance and strategic planning in business.

However, studies also point out limitations in AHP applications, such as industry- or company-specific constraints, which may reduce the generalizability of findings. This indicates the need for further research to validate and expand results across different contexts. Discussions on AHP's effectiveness emphasize its adaptability and flexibility but also the necessity of careful customization to specific business or industrial settings.

The diversity of MCDM methods suggests that researchers explore different approaches to solving complex decision-making problems. AHP and its variants, such as Fuzzy AHP, provide a structured process for quantifying and comparing criteria, while methods like TOPSIS or VIKOR offer alternative evaluation and selection frameworks.

Regarding AHP applications in the medical device manufacturing sector, studies suggest that AHP can be effective for product portfolio decision-making. This approach helps companies assess various aspects of product development, including technical, economic, and regulatory factors. However, a research gap remains regarding AHP's specific application in this industry, which warrants further exploration.

Future research plans to apply AHP in the medical device industry, particularly in manufacturing, distribution, and import. AHP appears promising for evaluating product portfolios, focusing on economic assessments related to the new MDR regulations. Key areas include assessing the feasibility of passing additional regulatory costs onto buyers and evaluating market demand and competitive advantages of products.

Reasons for Choosing AHP for This Research:

- Structured and quantitative decision-making: Essential for accurate economic evaluation in a complex business environment.
- Flexibility: Allows companies to adapt to dynamic industry changes, such as those introduced by MDR regulations.
- Integration of multiple perspectives: Financial, market, and regulatory factors are all considered for a comprehensive product assessment.

Research on AHP's application in the medical device sector will be crucial for advancing this method. The goal is not only to maximize its potential within this specific industry but also to provide an example of how AHP can be adapted for different industrial applications. This research will significantly impact strategic decision-making in the medical device sector, strengthening companies' ability to respond to market and regulatory changes in a structured and efficient manner.

Overall, AHP and its variants remain valuable decision-making tools across various business domains. Further adaptation and research in specific applications and industries will be key to fully leveraging their potential.

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The Impact of Economic Factors on the Level of Social Security in Polish Voivodships

Aldona MIGAŁA-WARCHOŁ^{1*}, Jolanta STEC-RUSIECKA^{1*} and Maciej WARCHOŁ²

¹ Rzeszow University of Technology, Rzeszow, Poland; amigala@prz.edu.pl; rusiecka@prz.edu.pl

² Jagiellonian University, Cracow, Poland; maciej.1.warchol@student.uj.edu.pl

* Corresponding author: amigala@prz.edu.pl; rusiecka@prz.edu.pl

Abstract: The purpose of this article is to examine the level of security within Polish society by analyzing crime rate data obtained from the Local Data Bank of the Polish Central Statistical Office. The data were collected for the year 2022 and cover individual provinces of Poland. In the second part of the study, a progressive stepwise regression model was developed to analyze the overall crime rate. The independent variables included: the rate of criminal offenses per 1,000 residents, the rate of economic crimes per 1,000 residents, the rate of crimes against life and health per 1,000 residents, the rate of crimes against personal freedoms, freedom of conscience and religion, sexual freedom and morals per 1,000 residents, and the rate of crimes against family and caregiving per 1,000 residents. The analysis was conducted using Statistica 13 software. The findings indicate that the factors significantly influencing the overall crime rate are: the rate of criminal offenses per 1,000 residents, the rate of economic crimes per 1,000 residents, and the rate of crimes against life and health per 1,000 residents. Additional analyses were performed to explore the relationship between crime rates and selected economic indicators.

Keywords: security; crime rates; economic measures; progressive stepwise regression; Poland.

JEL Classification: K42; E24; R11

1. Introduction

Analysis of crime statistics in the Central Statistical Office Local Data Bank is essential to understanding the state of security in Poland. These statistics can be used to establish trends, determine the effectiveness of law enforcement initiatives, and guide policymaking. This increases the potential for proper resource allocation and implementation of preventive interventions.

Local-level security refers to the conditions in an individual's immediate surroundings, such as places of residence, work, or study. Its core purpose is to minimize threats, including crime, accidents, or the adverse effects of natural disasters. Adequate local conditions provide individuals and communities with a sense of stability, fostering social and economic development.

One of the primary responsibilities of the state is to ensure the safety of all its citizens. The concept of local community safety is multifaceted. The highly complex network of

interconnections among the elements of this concept contributes to its multidimensional nature and makes precise definition challenging. Safety depends on the level of threats, which, in general terms, are defined as situations where there is an increased likelihood of loss of life, health, freedom, or material assets (Radkevyc et al., 2024).

A threat may arise from natural causes (e.g., the impact of natural forces) or be caused by another human being (Wyrebek, 2021). In this understanding, safety is a function of numerous diverse factors specific to a given community. Among these factors, two primary determinants can be distinguished: threat and risk. The state of threat and the level of risk play a significant role in assessing the sense of security within a community (Stevens et al., 2016). Choosing a place to live requires a critical evaluation of economic, social, and transportation factors, as well as the preferred lifestyle (Li et al., 2023).

Valla (2022) observed that many studies on the perception of security issues address the notion of perceived threats to security. This is particularly interesting because most researchers are inclined to analyze the perception of security threats rather than examine citizens' attitudes toward security services or their views on security programs. The author also highlighted a fundamental theoretical shift in security studies over the past fifty years: the focus of research has transitioned from an almost exclusive emphasis on military aspects to a broader scope encompassing new actors and sectors of security (Valla, 2022).

A single scientific theory cannot fully explain why individuals commit crimes, as criminal behavior is complex and multidimensional. The inability to develop a universal theory addressing all manifestations of criminality should not hinder efforts to analyze the influence of specific factors on crime rates. Some individuals become criminals not because of fundamentally different motivations, but because they calculate costs and benefits differently. Research conducted thus far on the correlation between crime rates and individuals' economic circumstances has yielded varied results. It is widely accepted that economic hardship motivates individuals to commit crimes. The most frequently cited economic factors influencing crime rates include unemployment, poverty, economic growth, income levels, and income inequality. Crime research uses a variety of economic models that incorporate a range of factors and variables (Bieniek et al., 2012).

The relationship between socioeconomic factors and crime is central to criminological research. Numerous studies have demonstrated how economic, social, and demographic conditions influence criminal behavior, revealing the complex relationships among these variables. Understanding these dynamics is essential to developing effective crime prevention strategies and addressing the root causes of criminal activity. Researchers have identified many socioeconomic factors—such as unemployment, poverty, educational attainment, and demographic characteristics—as significant contributors to changes in crime rates. Research emphasizes the need to consider the broader socioeconomic context when analyzing criminal behavior and formulating policies to reduce crime.

Socha and Migąła-Warchoł (2020) used 2016 crime data to create a stepwise regression model, and their study found correlations between crime rates and economic conditions. Such analyses could be used to identify high-crime areas, and law enforcement could focus patrols and preventive services where they are most needed (Mishra et al., 2024).

Janko and Popli (2015) examined the relationship between unemployment and crime in Canada using time series data from 1979 to 2006. The study found a significant correlation between unemployment and crime at regional and national levels. This confirmed that economic hardship, mainly unemployment, is a key factor influencing crime rates. This highlights the importance of addressing labor market challenges in crime prevention strategies (Janko & Popli, 2015).

Tarling and Dennis (2016) examined the relationship between crime and socio-economic conditions in England. They included variables such as unemployment, the Index of Multiple Poverty (IMD), average house prices, youth demographics, the resident population, and the transient population. The results showed that the resident population had a negative effect on both property and violent crime, while unemployment, IMD, the youth population, and the transient population were positively associated with crime rates (Tarling & Dennis, 2016).

The results of Kizilgol and Selim (2017) emphasize that there is a complex relationship between socioeconomic factors and crime. The positive correlation between variables such as GDP per capita, inflation, unemployment, and urban overcrowding suggests that economic instability and social pressure may contribute to higher crime rates. These results are consistent with other research findings on crime. The literature on the subject shows that economic factors are often associated with an increase in criminal behavior due to stressors such as financial insecurity, lack of opportunities, and social inequality. Furthermore, the urban context, with higher population density and potentially limited resources, seems to amplify these effects. This emphasizes the importance of comprehensive socioeconomic policies to address the root causes of crime, especially in rapidly urbanizing regions (Kizilgol & Selim, 2017).

Cerulli et al. (2018) examined economic factors influencing crime using data from the 50 U.S. states from 2000 to 2012. Their results indicated that education had a positive effect on crime, while wages had a negative effect (Cerulli et al., 2018).

Khan's study begins by examining the impact of poverty and unemployment on four specific types of crime: robbery, property theft, burglary, and motor vehicle theft. She uses crime data and social and economic variables from the United States. The study also examines how factors such as GDP, GDP per capita, imports, exports, urban growth, unemployment, and inflation have affected overall crime rates in the United States from 1960 to 2012 (Khan, 2024).

Brosnan (2018) analyzed the socio-economic factors influencing crime in Ireland using data from 2003 to 2012. The study found that factors such as income and detection rates had a positive impact on crime (Brosnan, 2018).

The majority of research employs data to analyze the socio-economic determinants of crime rates. Economists identify potential causal factors that significantly influence the prevalence of criminal activity across various societies (Shah & Kanwal, 2021).

Sheikh et al. (2021, 2022) employed cross-sectional analysis in their research to identify socio-economic determinants of crime among women and men. The results revealed that both crime-related and socio-economic factors significantly influence the type of crime committed (Sheikh et al., 2021; 2022).

Numerous studies examine the relationships between socio-economic factors and criminal behavior. The impact of socio-economic conditions, such as employment status, education level, and social inequalities, on crime rates has been investigated. Research indicates that social factors significantly influence the likelihood of committing crimes. The socio-economic system and criminal behavior are closely linked. People who do not have the necessary resources to succeed due to rapidly evolving technology live in poverty and experience inequality. This situation makes them more likely to engage in criminal behavior. Inflation, poverty, and unemployment are the three main indicators of economic crime (Sultan et al., 2024).

This article attempts to capture the relationship between selected economic factors and crime rates. The literature review explains the determinants of crime across different regions and time periods, focusing on the impact of economic variables such as income, GDP, and unemployment. These factors consistently emerge as significant predictors of crime. Additionally, the article discusses the influence of various social factors on criminal behavior.

The impact of economic factors on the level of social security in Polish voivodeships is an important topic, especially in the context of regional differences in economic development and living standards. Economic factors, including the unemployment rate, income per capita, regional investment, and the structure of the economy, can significantly affect disparities in the level of social security. Voivodeships characterized by lower unemployment and higher wages have greater financial resources to support social policy and help people at risk of social exclusion. On the other hand, regions with worse economic conditions may have greater challenges in providing adequate support to their residents, which can lead to increased social inequalities and a lower sense of social security. While focusing on crime data is key, it is equally important to consider the broader context that may also shape the security situation in Poland. Analysis of these phenomena allows for a better understanding of the impact of the economy on social stability and living conditions in different parts of Poland.

The article addresses two research questions:

Research question 1 - Which types of crime influence overall crime?

Research question 2 - Which economic factors influence the overall crime rate?

2. Methodology

The Pearson linear correlation coefficient and stepwise regression analysis were employed to explore the relationships among the variables under study. The initial method applied is the Pearson correlation coefficient. As noted by Berawi (2014), correlation quantifies the degree of association between two or more variables. The strength of this association is determined by the value of r . A higher correlation coefficient, as r approaches +1, indicates a strong positive relationship. The specific correlation coefficient values are presented in Table 1.

Pearson's correlation coefficient was used to assess the strength and direction of relationships between key economic indicators and the level of security across Polish

voivodeships. This statistical measure provides an initial insight into the degree of association before performing more complex regression analyses.

Table 1. Interpretation of the correlation coefficient (Hussin et al., 2014)

Coefficient value range	Strength of the correlation
1.0	Perfect
0.80-0.99	Very strong
0.60-0.79	Strong
0.40-0.59	Average
0.20-0.39	Weak
0.01-0.19	Very weak
0.00	No relationship

Stepwise regression involves sequentially adding explanatory variables to the model, prioritizing those that have the most significant effect on the dependent variable. This method evaluates the strength of the relationship between a single dependent variable and multiple independent variables. The strength of this relationship is indicated by the R-squared (R^2) value. R-squared, also known as the coefficient of determination, represents the proportion of the variation in the dependent variable (Y) that can be explained by the independent variables (X1-X3). The article presents two progressive stepwise regression models. First model for total crime rate and individual crime rates. Second model for total crime rate and economic factors.

The study adopts a regional perspective, analyzing the impact of economic conditions on social security at the voivodeship level in Poland. By integrating economic and social variables, the research provides a comprehensive understanding of the factors influencing security, which is often overlooked in broader national studies. The application of stepwise regression allows for the selection of the most significant economic predictors of social security, ensuring a data-driven model that allows better fitting. This approach enhances the robustness of the findings by refining variable selection, a methodology rarely applied in regional analyses of social security. By utilizing recent economic and social data from Polish voivodeships, this study provides up-to-date insights into the dynamic relationship between economic factors and the level of security. The findings offer valuable implications for policymakers aiming to design region-specific social programs.

3. Results

The purpose of the article is to analyze the level of security within Polish society using data on crime rates and economic indicators collected from the Local Data Bank of the Polish Central Statistical Office. The data were collected for the 2022 year for individual provinces of Poland.

The second table presents descriptive statistics of the variables analyzed – the mean, the minimum, the maximum, the standard deviation, the coefficient of variation and the coefficient of asymmetry for Polish provinces for 2022.

Table 2. Descriptive statistics of crime rates for Polish provinces for 2022

Variables	Descriptive Statistics					
	Mean	Min	Max	S	V	Assymetry
Crimes detected by the Police in total per 1,000 inhabitants	21.65	12.93	35.08	5.19	23.99	1.03
Crimes of a criminal nature detected by the Police per 1,000 inhabitants	12.47	6.81	19.57	3.27	26.23	0.43
Crimes of an economic nature detected by the Police per 1,000 inhabitants	6.27	2.98	17.79	3.34	53.34	2.98
Crimes detected by the traffic police per 1,000 inhabitants	1.90	1.39	2.49	0.32	16.81	0.50
Crimes against life and health detected by the Police per 1,000 inhabitants	0.37	0.26	0.52	0.07	19.82	0.48
Crimes against property detected by the Police per 1,000 inhabitants	10.72	6.46	16.86	2.83	26.36	0.40
Crimes detected by the Police against freedom, freedom of conscience and religion, sexual freedom and decency per 1,000 inhabitants	0.93	0.58	1.57	0.31	32.90	1.04
Crimes detected by the Police against family and care per 1,000 inhabitants	1.28	0.76	1.93	0.36	27.70	0.26
Crimes detected by the Police against public safety and transport safety per 1,000 inhabitants	2.08	1.56	2.69	0.34	16.43	0.44

The highest average values for Polish voivodships (with the exception of the total crime rate – 21.65%) were obtained for the criminal crime rate (12.47%) and the crime rate against property (10.72%). The smallest values were obtained for the crime rate against life and health (0.37%), as well as for the crime rate against freedom, freedom of conscience and religion, sexual freedom and morals (0.93%). The smallest diversification for Polish provinces occurs in the rate of crimes detected by the Police against public safety and transport safety per 1,000 inhabitants (coefficient of variation is equal to 16.43%), while the largest features in the crimes rate of economic nature detected by the Police per 1,000 inhabitants (coefficient of variation is equal to 53.34%). The highest value is characteristic to the overall crime rate and it is equal to 35.08. The lowest value is characteristic to the crime rate against life and health and it is equal to 0.26.

The third table presents results of progressive regression, obtained using the Statistica 13 program. As a result of the research conducted, it was obtained that the indicators affecting the overall crime rate are: crimes rate of a criminal nature detected by the Police per 1,000 inhabitants, crimes rate of an economic nature detected by the Police per 1,000 inhabitants and crimes rate against life and health detected by the Police per 1,000 inhabitants (indicated by the highest values of the estimated parameter b - due to the statistically significant values). It has been verified that the residuals of the model have a normal distribution.

Table 3 displays an R-squared (R^2) value of 0.99, indicating that 99.99% of the variation in the dependent variable (Y) can be explained by the independent variables (X1-X3) combined. The regression model presented in Table 3 provides estimates of the marginal effects for each independent variable as well as model fit statistics. The marginal effects

illustrate the expected changes in the overall crime rate resulting from a one-unit increase or decrease in each independent variable.

Table 3. Summary of regression of the dependent variable: total crimes detected by the Police per 1,000 inhabitants

	Summary of regression of the dependent variable: total crimes detected by the Police per 1,000 inhabitants R = 0.99861272 R ² = 0.99722737 Corrected R ² = 0.99653421					
	b*	Std. Error b*	b	Std. Error b	t(12)	p
Intercept			0.974259	0.446494	2.18202	0.049714
Crimes of a criminal nature detected by the Police per 1,000 inhabitants	0.679815	0.016298	1.079672	0.025885	41.71030	0.000000
Crimes of an economic nature detected by the Police per 1,000 inhabitants	0.630629	0.015427	0.979073	0.023952	40.87715	0.000000
Crimes against life and health detected by the Police per 1,000 inhabitants	0.041018	0.016360	2.928482	1.168018	2.50722	0.027548

The model fit statistics help determine which independent variables have the strongest individual predictive power for the overall crime rate. It is evident that the rate of criminal offenses detected by the Police ($b = 1.08$) has the most significant impact on the overall crime rate. The marginal effects indicate that a one-unit increase in the economic crime rate is expected to raise the overall crime rate by 0.98 units, while a one-unit increase in the rate of crimes against life and health is projected to increase the overall crime rate by 2.93 units.

The table 4 presents descriptive statistics of the particular economic indicators – the mean, the minimum, the maximum, the standard deviation, the coefficient of variation and the coefficient of asymmetry for Polish provinces for 2022.

Table 4. Descriptive statistics of economic indicators for Polish provinces for 2022

Variable	Descriptive Statistics					
	Mean	Min	Max	S	V	Assymetry
GDP per capita	72,864.75	55,125.00	127,791.0	18,759.16	25.75	1.76
Unemployment rate	5.90	2.90	8.8	1.87	31.63	0.13
Capital expenditure per capita	9,466.63	6,701.00	14,828.0	2,044.29	21.59	1.12
Inflation rate	114.44	113.10	116.1	1.01	0.88	0.37
Average monthly salary	6,286.70	5,662.53	7,913.1	595.12	9.47	1.49

Table 5 displays the correlation coefficients between the total crime rate and selected economic variables. This section of the article explores the relationship between the overall crime rate and economic indicators such as GDP per capita, unemployment rate, investment expenditures per capita, inflation rate, and average monthly salary. The correlation matrix (Table 5) reveals that a statistically significant correlation exists only between the overall crime rate and the unemployment rate ($r = -0.60$), as well as between the overall crime rate and the average monthly salary ($r = 0.53$).

The analysis indicates that wealthier provinces are more susceptible to criminal activity. Consequently, the authorities in these regions should consider allocating resources to mitigate and prevent such incidents.

Table 5. Coefficients of correlations between crimes detected and economic indicators

Variables	Correlations, marked with correlation coefficients, are significant with $p < 0.05$					
	Crimes detected by the Police in total per 1,000 inhabitants	GDP per capita	Unemployment rate	Capital expenditure per capita	Inflation rate	Average monthly salary
Crimes detected by the Police in total per 1,000 inhabitants	1.00	0.48	-0.60	0.44	-0.41	0.53
GDP per capita	0.48	1.00	-0.71	0.86	-0.27	0.91
Unemployment rate	-0.60	-0.71	1.00	-0.59	0.11	-0.65
Capital expenditure per capita	0.44	0.86	-0.59	1.00	-0.48	0.82
Inflation rate	-0.41	-0.27	0.11	-0.48	1.00	-0.34
Average monthly salary	0.53	0.91	-0.65	0.82	-0.34	1.00

The table 6 presents results of progressive regression, obtained using the Statistica 13 program. As a result of the research conducted, it was obtained that the economic indicator affecting the overall crime rate is the unemployment rate.

Table 6. Summary of regression of the dependent variable: total crimes detected by the Police per 1,000 inhabitants

	Summary of regression of the dependent variable: total crimes detected by the Police per 1,000 inhabitants $R = 0.69537002$ $R^2 = 0.48353946$ Corrected $R^2 = 0.40408399$					
	b*	Std. Error b*	b	Std. Error b	t(13)	p
Intercept			239.6666	117.9582	2.03179	0.063133
Unemployment rate	-0.562221	0.200448	-1.5644	0.5577	-2.80482	0.014892
Inflation rate	-0.353902	0.200448	-1.8245	1.0334	-1.76555	0.100932

The results of the study indicate the relationship that the richer the region is, the greater the threat to its residents' security. In turn, the analysis of the relationships between the overall crime rate and the selected economic measures made it possible to state that the unemployment rate and average monthly salary statistically significantly influence the overall crime rate in Polish provinces. From the results obtained, a statistically significant moderate dependence occurred first between the unemployment rate (negative one) and the total crime rate, second between average monthly salary (positive one) and the total crime rate.

4. Discussion

The objective of this study was to examine the security level of Polish society by analyzing crime rates sourced from the Local Data Bank of the Central Statistical Office. The analysis revealed that the most dangerous provinces were those with the highest average monthly salaries. A stepwise progressive regression model developed for the total crime rate identified that the overall crime rate was primarily influenced by the criminal crime rate, the rate of economic crimes, and the rate of crimes against life and health, as detected by the Police. Consequently, it is crucial to allocate significant resources toward combating these specific types of crime.

The study results highlight a relationship suggesting that the wealthier a region, the higher the risk to its residents' security. Additionally, the analysis of the correlation between the overall crime rate and selected economic indicators revealed that the unemployment rate and average monthly salary have a statistically significant impact on crime rates across Polish provinces. Specifically, the findings show a moderate, statistically significant negative correlation between the unemployment rate and the total crime rate, and a moderate positive correlation between the average monthly salary and the total crime rate.

The study results highlight the complex relationship between socio-economic factors and crime rates in Polish regions (voivodeships). The analysis shows that regions with higher average monthly wages exhibit higher crime rates, which highlights the paradoxical relationship between economic prosperity and security. The significant impact of unemployment and average wages on overall crime rates further highlights the details of how economic conditions affect criminal behavior. In particular, the negative correlation with unemployment and the positive correlation with wages indicate the need for targeted interventions that address the root causes of crime in both affluent and less affluent areas.

These results suggest that more affluent regions need to develop tailored crime mitigation strategies that focus on different types of crime. The strategy should include crimes that occur most frequently in these areas, such as economic crimes and crimes against life and health. Effectively allocating resources to combat these specific problems is crucial to improving public safety.

What specific measures can policymakers implement to address the link between economic growth, higher average wages, and increased crime scene in wealthier regions? Furthermore, how can targeted crime prevention strategies be tailored to the unique socioeconomic dynamics of these regions while ensuring equitable distribution of resources to less affluent areas? What role should local governments, law enforcement agencies, and community organizations play in developing a holistic approach to reducing crime without compromising economic development?

5. Conclusions

The study highlights the importance of adopting a balanced and region-specific approach to crime prevention, recognizing the diverse socio-economic dynamics at play. Policymakers must consider not only economic growth but also the unintended security challenges it may bring. Cooperation between local governments, law enforcement, and

community organizations will be essential in crafting holistic solutions that enhance social stability while maintaining economic progress.

Conflict of interest: none

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Artificial Intelligence in Multinational Corporations: A Systematic Review of Strategic Integration and Applications

Chinyere OKECHUKWU* and Pavel BACHMANN

University of Hradec Kralove, Hradec Kralove, Czech Republic; chinyere.okechukwu@uhk.cz;
pavel.bachmann@uhk.cz

* Corresponding author: chinyere.okechukwu@uhk.cz

Abstract: Multinational corporations (MNCs) play a crucial role in shaping global business trends and driving innovation across industries. As artificial intelligence (AI) continues to transform the business landscape, its strategic and managerial applications within MNCs are becoming increasingly significant. AI enhances decision-making, optimizes processes, and fosters competitive advantage by automating complex tasks, enabling predictive analytics, and improving operational efficiency. This systematic review examines the integration of AI within MNCs from 2021 to 2024, employing the PRISMA methodology. The study synthesizes findings from peer-reviewed articles indexed in Web of Science, focusing on 27 distinct functional applications of AI. The primary objective is to identify strategic and managerial applications of AI in MNCs and analyze their impact on corporate operations. Through a combination of bibliometric analysis and qualitative synthesis, the review highlights key trends in AI adoption, strategic implications, and operational transformations. Key findings reveal diverse applications of AI across supply chain optimization, market intelligence, human resource management, and customer experience enhancement. The study underscores AI's evolving role in fostering strategic agility and sustaining competitive advantage in global markets, while also addressing ethical considerations and implementation challenges.

Keywords: artificial intelligence (AI); strategic management; business intelligence; AI adoption; multinational corporation

JEL Classification: O32; O15; M21

1. Introduction

Multinational corporations (MNCs) play a pivotal role in shaping global business trends, driving technological advancements, and influencing economic development. Due to their extensive operations, complex supply chains, and cross-border market presence, MNCs serve as frontrunners in adopting and integrating emerging technologies. Among these, artificial intelligence (AI) has emerged as a transformative force, revolutionizing business processes, optimizing decision-making, and enhancing strategic agility.

Over the past two decades, AI has experienced unprecedented progress, accelerating advancements in automation, machine learning, and data-driven analytics. AI technologies

have reshaped industries by improving operational efficiency, fostering innovation, and enabling organizations to gain competitive advantages (Dogru & Keskin, 2020). However, while AI adoption is widespread, its strategic and managerial applications in MNCs remain a subject of ongoing research and debate.

This study aims to systematically explore the role of AI in MNCs by identifying key applications and assessing their implications for corporate strategy and management. Through a systematic review of scholarly literature published between 2021 and 2024, this research provides insights into the prevalent AI applications across various business functions and their strategic relevance.

1.1. Multinational Corporations

Multinational corporations (MNCs) are companies that operate in multiple countries while maintaining a centralized management structure. They typically have headquarters in one country but conduct business through subsidiaries, branches, or joint ventures in international markets. MNCs leverage their global presence to access diverse markets, optimize resource allocation, and benefit from economies of scale. Key characteristics of MNCs are:

1. global operations, eg presence in multiple countries with production, sales, and service networks (Kostova et al., 2016);
2. centralized management, strategic decisions are coordinated from headquarters while allowing regional adaptations (Kostova et al., 2020);
3. large-scale influence, MNCs dominate industries due to their vast financial and technological resources (Marano et al., 2017);
4. standardized and localized strategies, balances between global branding and local market customization (Beugelsdijk et al., 2018);
5. technological investment, heavy focus on innovation, AI integration, and R&D (Amankwah-Amoah et al., 2015);
6. complex supply chains, management of extensive logistics and production networks (Bhattacharyay et al., 2023);
7. economic and regulatory impact, MNCs influence global trade policies and regulatory frameworks. (Odunlami et al., 2015).

Given their complexity, MNCs are at the forefront of AI adoption, leveraging its capabilities to enhance efficiency, decision-making and market responsiveness.

1.2. Artificial Intelligence

AI was first introduced as a concept by McCarthy at the Dartmouth Conference in 1956 (McCarthy et al., 2006), marking the beginning of intensive research in the field. AI encompasses a broad range of technologies that enable machines to perform cognitive functions such as problem-solving, pattern recognition, and decision-making (Hashimoto et al., 2018). Despite extensive research, there is no universally accepted definition of AI;

instead, it is commonly understood as an umbrella term for various computational techniques that replicate human-like intelligence (Zhang & Lu, 2021).

With the rise of Industry 4.0 AI adoption has accelerated due to advancements in data availability, computational power, and interconnected systems (De Sousa et al., 2019). AI applications now permeate nearly all aspects of business and everyday life, from automated customer service chatbots to real-time data analysis tools (Brill et al., 2019). Key AI technologies such as machine learning, natural language processing, and computer vision are widely applied across industries, driving efficiency and innovation (Abioye et al., 2021).

While AI research spans numerous domains, this study focuses on its broad applications in MNCs, examining how these corporations integrate AI-driven solutions to enhance strategic decision-making and operational performance.

1.3. Artificial Intelligence Applications in Multinational Corporations

AI is reshaping MNC operations across multiple domains. Below are key areas where AI has a significant impact:

1. Automation of Routine Tasks – AI-powered automation enhances efficiency in processes such as data entry, invoice processing, customer support, and supply chain management (Dogru & Keskin, 2020).
2. Data-Driven Decision-Making – AI enables advanced analytics, identifying patterns and trends that support strategic corporate decisions (Fernando, 2023).
3. Personalization and Customer Experience – AI enhances customer engagement through personalized recommendations, predictive analytics, and automated support systems (Dogru & Keskin, 2020).
4. Predictive Analytics and Forecasting – AI improves demand forecasting, risk assessment, and inventory optimization in global supply chains (Jahin et al., 2023).
5. Supply Chain Optimization – AI-driven algorithms enhance logistics, inventory management, and operational efficiencies, reducing costs and increasing reliability (Ivanov et al., 2021).
6. Talent Management and Recruitment – AI assists in hiring processes, performance evaluation, and workforce planning while reducing biases in recruitment (Kim et al., 2022).
7. Enhancing Innovation – AI facilitates research and development, rapid prototyping, and digital transformation initiatives (Kim et al., 2022).
8. Risk Management – AI-powered monitoring systems detect anomalies and mitigate operational risks in global markets (Jahin et al., 2023).
9. Globalization and Market Expansion – AI aids in market analysis, localization strategies, and consumer behavior prediction, supporting international growth (Kim et al., 2022).
10. Sustainability and ESG Initiatives – AI contributes to sustainability by optimizing resource usage, improving energy efficiency, and enhancing corporate ESG strategies (Jahin et al., 2023).

Given the increasing reliance on AI in MNC operations, this study seeks to address the following research question: What are the key strategic and managerial applications of AI in multinational corporations, as reflected in contemporary research literature? To answer this question, the study conducts a systematic review of academic literature, mapping the state-of-the-art in AI applications within MNCs. The review identifies trends, challenges, and opportunities associated with AI integration, providing insights into its evolving role in global business strategy.

2. Methodology

The systematic literature review is characterized as a mixed approach (Zhang et al, 2020) since it combines quantitative, i.e. bibliometric analysis (Donthu et al., 2021) and qualitative technique, such as content analysis of papers (Page et al., 2021a). The study was carried out in the below consequent steps:

1. Determination of the database selection criteria and dataset fields (the database used was Web of Knowledge because its long and steady standing as a trans-disciplinary index of the most referenced periodicals (Singh et al, 2021);
2. Formulation of inclusion and exclusion criteria for publications analyzed;
3. Keyword database searching (the title, abstract, and keywords referencing to concepts (for search settings as inclusion/exclusion criteria see table 1 and table 2), the searching was executed on Feb 28, 2025;
4. Screening of keyword database searching results, the goal was to verify factual relationship with the study goal, unlike this was performed by human screening exclusively;
5. Bibliometric and systematic analysis was performed by the authors with the support of online Web of Science interface and in two steps as recommended by Page et al. (2021b).

The gathered references were stored and processed using Mendeley online reference manager (Takatori, 2016).

Table 1. Search settings

Item	Settings	Rationale
Indexing service	Web of Science	Quality of materials published
Database	Web of Science Core Collection (1945-present)	Leading publications, full indexation and searchability
Edition	SCI-EXPANDED SSCI ESCI	Elimination of documents pertaining to irrelevant research areas
Exact search	disabled	Abridgement and simplicity of search queries, however without reduction of the scope of documents retrieved

Table 2. Search queries

Item	Query segment	Rationale
Publication Years	PY=(2021-2024)	Broad research period, enabling determination of time trends
Language	LA=("ENGLISH")	Practical reasons: language gap
WOS Index	EDN=("WOS.SCI" OR "WOS.SSCI" OR "WOS.ESCI")	Elimination of irrelevant research areas
WOS Categories	TASCA "MANAGEMENT" OR "ENGINEERING ENVIRONMENTAL" OR "BUSINESS" OR "" OR "OPERATIONS RESEARCH MANAGEMENT SCIENCE" OR "HEALTH" OR "ECONOMICS" OR "BUSINESS FINANCE" OR "TRANSPORTATION SCIENCE TECHNOLOGY" OR "TRANSPORTATION" OR "PUBLIC ADMINISTRATION" OR "LAW" OR "POLITICAL SCIENCE")	Elimination of irrelevant research areas
Research Areas	SJ=("ENVIRONMENTAL SCIENCES ECOLOGY" OR "BUSINESS ECONOMICS" OR "TRANSPORTATION" OR "OPERATIONS RESEARCH MANAGEMENT SCIENCE" OR "PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH" OR "PUBLIC ADMINISTRATION" OR "GOVERNMENT LAW")	Elimination of irrelevant research areas
Keywords	TS="Artificial Intelligence*" OR TS=("AL " AND "ML*")	Focus on Artificial Intelligence Application
	TS=("emergency" OR "medical")	Elimination of items related to "Emergency Medical Service"
	TS=("Multinational corporation*" OR "Multination Enterprise*")	Focal on MNC

Note: The resulting search query was formulated by concatenating the above query segments in the WoS Advance Search Interface with the following syntax: #1 AND #2 AND #3 AND #4 AND #5 AND #6 NOT #7 AND #8

3. Results

3.1. Keyword Search and Searching Results

The total of 117 results obtained as specified above were screened for compliance with the inclusion/exclusion criteria as specified above. The screening led to a resulting portfolio of 27 publications rendered in the lower bold-framed nod of the PRISMA Flowchart (Annex), which were then entered into the quantitative bibliometric analysis and the following qualitative systematic analysis.

3.2. Bibliometric Analysis

In the resulting portfolio we identified 15 survey studies, 9 review studies and 3 case studies. The portfolio comprises majority of empirical studies, which indicates that empirical approach is most applied on this subject. The most frequented keywords identified in the resulting portfolio were AI (17 occurrences), Medicine (9); MNCs (4). This makes us conclude that the AI application is the most accentuated, followed by the aspect of the MNC. We identified 12 qualitative oriented articles in the portfolio, versus 15 quantitative oriented ones. This leads us to assume that quantitative aspect is prevailing within the scope of problems related to AI aspect of MNCs operations. The results of bibliometric analysis are summarized in Figure 1.

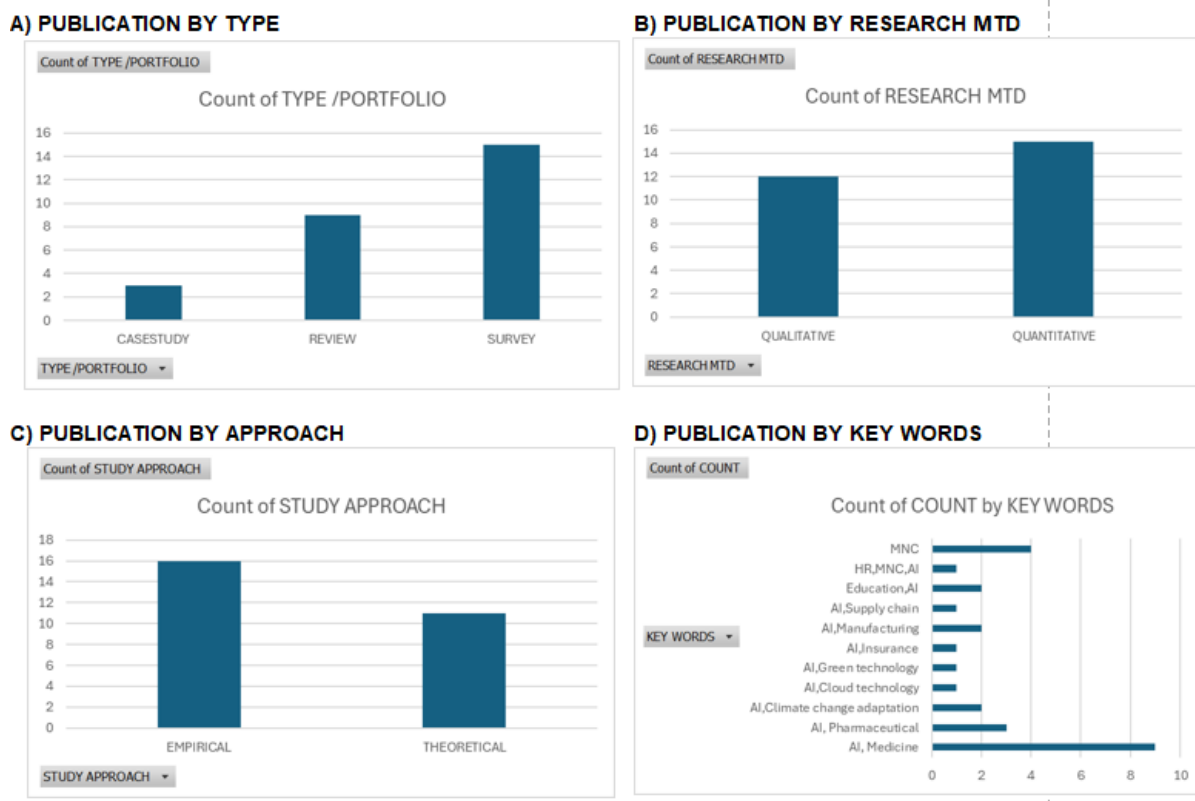


Figure 1. Bibliometric analysis of the resulting portfolio

3.3. Systematic Analysis

Following the quantitative bibliometric analysis, the publication portfolio entered into qualitative analysis stage for systematic review as defined by Johnstone (2020a), which was the main goal of this study (no quantitative analysis was performed within the framework of the systematic review). It consisted in examining the specific operations with strategic management orientation dealing with AI applications in MNCs.

Table 3 provides a list of the dominant aspects of AI applications as treated in each of the resulting portfolio publications.

From the findings of the reviews, the paper points out the following: In human resources, AI improves recruitment, performance evaluation, and employee engagement by automating

repetitive tasks and providing data-driven insights (Malik et al., 2023; Budhwar et al., 2022). However, concerns about bias in AI-driven hiring processes persist.

Table 3. Dominant aspects of AI applications in MNCs businesses

Business Application Area	Systematic Analysis Results
Human resources and Workforce Management	AI applications enhance the efficiency of HR processes, support employee experience (EX) and engagement (EE). They assist in recruitment, performance evaluation, and automation of repetitive HR tasks. (Malik et al., 2023; Budhwar et al., 2022)
Customer Experience & Sales	AI enables automation of customer support, personalization of marketing offers, and predictive analytics to improve sales. (Aerts et al., 2022; Osburg et al., 2022)
Supply Chain & Logistics	AI is used for warehouse management optimization, inventory control, and demand forecasting. (Veres, 2023; Oldemeyer et al., 2024)
Strategic Decision-Making & Business Intelligence	AI enables the analysis of large data volumes for better decision-making, scenario modeling, and automated reporting. (Celsi, 2023; Filho et al., 2022)
Cybersecurity & IT Infrastructure	AI enhances security in SaaS and cloud platforms, detects threats, and enables predictive system monitoring. (Swetnam et al., 2024)
Legal & Ethical Considerations	Companies address legal aspects of AI, particularly in data protection (GDPR) and decision-making transparency. (Dexe, 2022)
Sustainability & Climate Impact	AI is used for modeling climate change impacts, optimizing energy networks, and supporting sustainable development. (Filho et al., 2022; Celsi, 2023)

In customer experience and sales, AI personalizes marketing offers, automates customer support, and enhances predictive analytics to improve sales performance (Aerts et al., 2022; Osburg et al., 2022). While AI-driven interactions improve efficiency, over-reliance on automation may reduce the human element in customer service.

AI optimizes supply chain and logistics through predictive demand forecasting, warehouse automation, and inventory control, reducing costs and improving operational resilience (Veres, 2023; Oldemeyer et al., 2024). However, data security concerns and algorithmic biases in demand forecasting remain challenges. Similarly, AI-driven business intelligence enhances strategic decision-making by analyzing vast data volumes and modeling business scenarios, enabling faster and more informed choices (Celsi, 2023; Filho et al., 2022). The main concern is ensuring the transparency and reliability of AI-generated insights.

Cybersecurity benefits from AI-driven threat detection and predictive system monitoring, particularly in cloud computing and SaaS environments (Swetnam et al., 2024). Despite its advantages, AI also enables increasingly sophisticated cyber threats, requiring continuous adaptation. Legal and ethical considerations, particularly regarding AI's role in GDPR compliance and decision-making transparency, are critical areas of focus (Dexe, 2022). However, AI governance frameworks remain inconsistent across regions, creating regulatory uncertainty.

AI also contributes to sustainability by modeling climate impacts, optimizing energy networks, and promoting responsible resource management (Filho et al., 2022; Celsi, 2023). While AI helps drive environmental initiatives, the computational energy demand of AI systems raises concerns about their carbon footprint.

Overall, while AI significantly improves business efficiency and decision-making, ethical risks, regulatory challenges, and sustainability concerns must be addressed to maximize its benefits.

4. Discussion

AI is transforming business operations across various domains, improving efficiency, automation, and decision-making. It enhances human resource management by streamlining recruitment and employee engagement, optimizes customer experience through personalization and predictive analytics, and improves supply chain management with advanced forecasting and automation (Malik et al., 2023; Budhwar et al., 2022; Aerts et al., 2022; Veres, 2023). AI also supports strategic decision-making, strengthens cybersecurity, and plays a role in sustainability efforts, despite ongoing concerns about regulatory compliance, transparency, and ethical considerations (Celsi, 2023; Swetnam et al., 2024; Dexe, 2022). These findings align with existing research on AI's growing role in business. Studies suggest that AI-driven HR solutions reduce hiring biases and improve employee retention, though biases in algorithms remain a concern (Budhwar et al., 2022). AI-powered customer engagement has been widely adopted, yet some studies indicate that excessive automation may diminish customer trust (Osburg et al., 2022). Supply chain optimization through AI has proven effective, particularly in predictive analytics, but limitations in data quality can affect forecasting accuracy (Oldemeyer et al., 2024). Furthermore, while AI enhances cybersecurity, it also enables more sophisticated cyber threats, creating an ongoing challenge for IT security (Swetnam et al., 2024).

This study has several limitations. The analysis primarily relies on Web of Science (WoS) sources, excluding potentially valuable insights from Scopus or other databases. Additionally, the time frame is limited, meaning some recent advancements in AI applications may not be fully captured. The methodology, including keyword selection, may not have been entirely exhaustive, potentially omitting relevant studies. Future research should broaden database coverage, refine search parameters, and explore the long-term impact of AI adoption across industries.

5. Conclusions

The research highlights the transformative role of AI in multinational corporations (MNCs), offering critical insights into its strategic and managerial applications. AI enhances decision-making, automates operations, and drives competitive advantage across key business functions such as human resources, customer experience, supply chain management, and cybersecurity. The study underscores AI's growing significance in fostering agility and efficiency, while also acknowledging ethical and regulatory challenges.

This research is vital as it provides a structured analysis of AI adoption in MNCs, helping organizations navigate its integration for optimal business performance. By systematically reviewing AI applications, the study informs corporations on best practices, potential risks, and emerging trends. The findings contribute to the broader discourse on digital transformation, equipping businesses with knowledge to enhance AI-driven strategies.

For future insights, the study emphasizes the need for ethical AI frameworks, regulatory alignment, and workforce adaptation to AI-driven processes. Given AI's rapid evolution, continuous research is essential to assess its long-term impact on MNCs and refine AI strategies for sustainable and responsible corporate growth.

Conflict of interest: none

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International Trade of Selected Agri-Food Products Between Poland and The Czech Republic

Anna OLSZAŃSKA¹, Anna Sylwia KOWALSKA¹, Klaudia PASKUDZKA¹, Joanna SZYMAŃSKA¹ and Martin KRÁL^{2*}

¹ Wrocław University of Economics and Business, Wrocław, Poland; anna.olszanska@ue.wroc.pl; anna.kowalska@ue.wroc.pl; klaudia.paskudzka@ue.wroc.pl; joanna.szymanska@ue.wroc.pl

² University of Hradec Králové, Hradec Králové, Czechia; martin.kral.2@uhk.cz

* Corresponding author: martin.kral.2@uhk.cz

Abstract: The aim of this study is to analyze and assess the development of trade in agri-food products between Poland and the Czech Republic in 2014-2023. The study focuses on the identification of key product groups, analysis of the competitiveness of Polish exports and the impact of non-tariff barriers on trade dynamics. The study uses basic methods of statistical analysis, relying on data from the Ministry of Agriculture and Rural Development. The analysis covers both the scale of trade turnover and its structure, taking into account the main determinants of trade, such as regulatory policy, consumer preferences and Poland's integration with the European Union. The most important conclusions indicate a dynamic growth of Polish agri-food exports to the Czech Republic, especially in the poultry meat, dairy and pork sectors. Despite the tightening of administrative requirements in the Czech Republic after 2016, Poland has maintained its competitiveness through flexible adaptation strategies and the use of cost advantages. Key implications include the need to further diversify exports, analyzing the impact of EU trade policy on bilateral trade and monitoring potential regulatory risks. The results obtained can provide a basis for further research on the adaptation mechanisms of Polish exporters in the face of a changing market environment and for the formulation of trade policy recommendations.

Keywords: international trade; competitiveness; agri-food products

JEL Classification: F14; Q17; Q18

1. Introduction

Trade in agri-food products between Poland and the Czech Republic is growing steadily. Poland has become the second largest food exporter to the Czech Republic after Germany. Since Poland's accession to the European Union, exports to this country have been steadily increasing (Michalczyk, 2010). This is confirmed by a significant increase in the value of agri-food exports (Szczepaniak, 2019). However, the dynamics of this trade relationship is affected by various barriers. Before 2016, the growth of Polish agri-food exports to the Czech Republic was higher than the overall growth of exports to the European Union. This suggests that it was the various barriers, such as misidentified quality or phytosanitary issues, that did not have a significant impact on the expansion of Polish exports to the Czech market (Pawlak & Smutka, 2022). However, the situation changed in 2016, when the Czech authorities

introduced stricter administrative requirements that can be considered traditional soft non-tariff barriers (Ambroziak & Grochowska, 2018). These measures affect the growth and flow of Polish agri-food exports to the Czech market.

The existing literature on barriers to agri-food trade between Poland and the Czech Republic provides valuable insights. The main agri-food products exported from Poland to the Czech Republic are: poultry meat, bread and bakery products, tobacco products, pet food, cheese and cottage cheese, chocolate and chocolate products, pork meat and butter (Bureau of Analyses and Strategies. National Agricultural Support Centre, 2024). A fact about the dairy segment should be added at this point. Spatial market integration results in long-term price relations for milk and skimmed milk powder between Poland and the Czech Republic (Roman & Kroupová, 2022). Polish trade in meat products is a key component of the economy, exerting a significant influence on both domestic and international markets. In 2023, the sector was dominated by poultry meat, which had the highest share of trade. Nevertheless, an analysis of the literature indicates a significant growth rate of the entire meat products export sector in recent years. As Firlej (2013) notes, the growth of exports has not been limited to poultry but has also included other types of meat, highlighting the growing role of this industry in the structure of international trade. This reflects both the agricultural strengths of both countries and market demand (Michalczyk, 2010). This is particularly important because overall, international trade in meat products has undergone significant transformations in recent years. Poland's integration into the European Union has led to many changes in the structure of trade and domestic production, which has particularly benefited poultry producers and processors. While beef exports have increased, the pork market has faced challenges and Poland has become a net importer of pork (Olszańska, 2016). It is still worth mentioning that a deeper analysis of the export structure indicates a competitive advantage of the Polish food industry (Bogdan et al., 2015), which allows us to conclude that Poland has a high capacity to respond to consumer demand in the Czech market.

Research strongly emphasizes factors influencing intra-industry trade in agricultural products between Poland and EU countries, including the Czech Republic (State Research Institute, 2018). Elements such as trade intensity, economic development and language similarities stand out (Łapińska, 2014). For non-EU countries, determinants of Polish agri-food exports include GDP level, geographical distance, agricultural value added and preferential trade agreements (Sapa & Drożdż, 2019). During the COVID-19 pandemic, Polish agri-food trade showed resilience, with exports declining by only 3% in Q2 2020 compared to larger declines in other sectors (Maśniak & Jędruchiewicz, 2024). This research highlights the complexity and importance of international trade relations in the agricultural sector for Poland and its trading partners, including the Czech Republic.

While the existing literature provides a comprehensive understanding of the barriers faced by Polish agri-food exporters in the Czech market, it is also important to consider the broader factors that contribute to the competitiveness and diversification of Polish agri-food exports.

2. Methodology

The accession of Poland and other Central and Eastern European countries to the European Union has opened new perspectives for the development of international trade both inside and outside the Union. The aim of the study is to analyze and evaluate the development of trade contacts between Poland and the Czech Republic in 2014–2023 on the example of agri-food products. A group of selected several product groups playing a significant role in trade between the two countries were analyzed in detail. Data for the analyses were obtained from the databases of the Ministry of Agriculture and Rural Development. The study used basic methods of statistical data analysis.

3. Results

3.1. Scale of Trade in Agricultural and Food Products Between Poland and the Czech Republic

Since Poland's entry into the EU common market, a systematic increase in international trade turnover has been noticeable (Figure 1). This was true for both exports and imports. On the export side, an almost sixfold increase was recorded between 2004 and 2023, and on the import side an approx. 4.8-fold increase was recorded. Compared to the scale of turnover, its balance took on relatively small values and ranged from – EUR 26.2 billion in 2008 to EUR 10.5 billion in 2020.

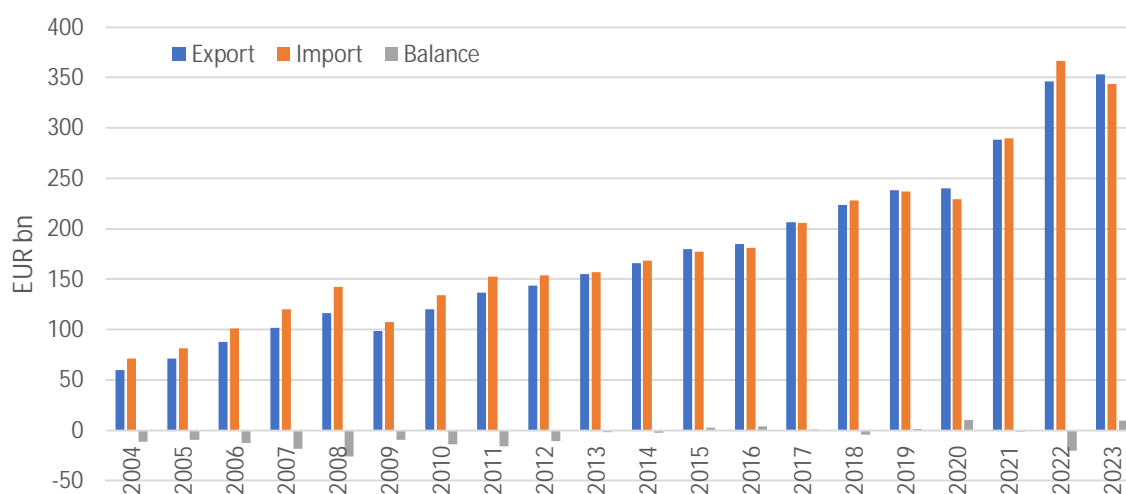


Figure 1. Poland's total foreign trade (exports, imports and balance) 2004–2023 (EUR bn.), own processing based on data from the Ministry of Agriculture and Rural Development (Ministerstwo Rolnictwa i Rozwoju Wsi, 2013, 2014, 2015, 2016, 2017, 2018, 2020, 2021, 2022, 2023)

Trade in agricultural and food products constitutes a significant item in Poland's total trade. Its share in exports has been gradually increasing over the years and ranged from 10% in 2004 to 14.8% in 2023. In imports, the share also increased, but to a lesser extent and took lower values - from 6.8% (2004) to 9.8% (2023). In 2023, exports will reach an all-time high of €52.1bn and imports €33.4bn. In none of the years analyzed in Figure 2 was there a negative balance in international trade in agri-food products and in 2023 it reached €18.7bn. In total, exports of agri-food products from Poland increased by nearly ten times and imports by more than 7.5 times. This phenomenon should be viewed positively. On the one hand, it is possible to make fuller and better use of the potential of Polish agriculture and develop selected

directions of production. On the other hand, free import of goods enriches the domestic market, but also prompts to improve the competitiveness of Polish farmers and food producers. Obviously, negative phenomena may also be pointed out, including, inter alia, an increase in the intensity of agriculture, increasing the scale of concentration of production and its regionalization in the context of the burden on the natural environment, if only in the issue of high water consumption connected with animal production (which uses very large amounts of water and occupies an important position in exports).

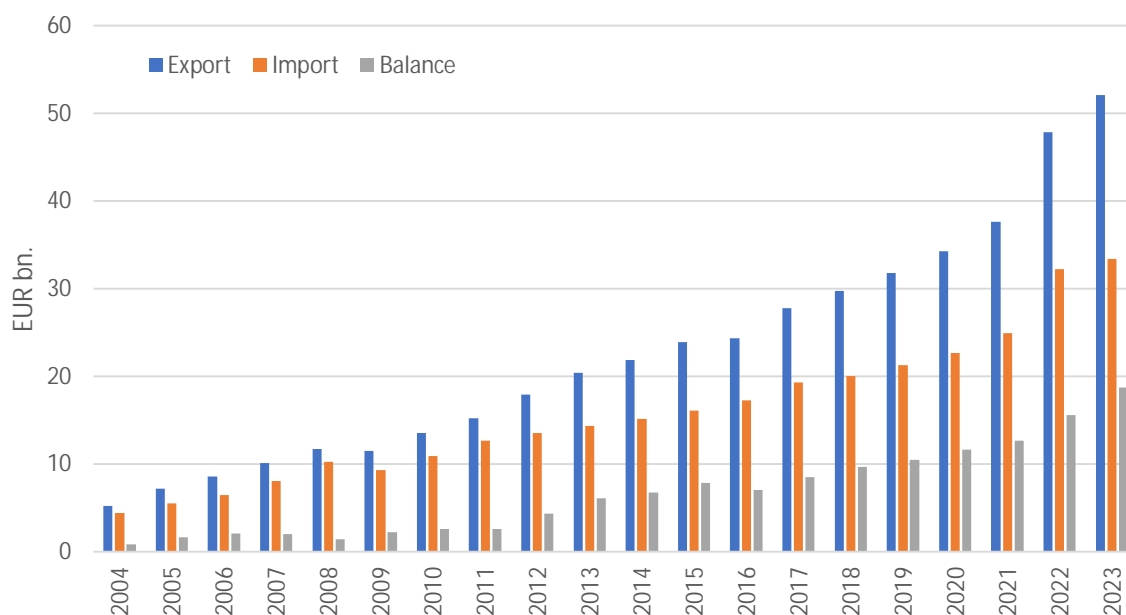


Figure 2. Poland's foreign trade in agri-foodstuffs (exports, imports, balance) 2004-2023 (EUR bn.), own processing based on data from the Ministry of Agriculture and Rural Development (Ministerstwo Rolnictwa i Rozwoju Wsi, 2013, 2014, 2015, 2016, 2017, 2018, 2020, 2021, 2022, 2023)

Such a significant increase in the scale of international trade was due to the increase in trade with EU countries, but also with third countries. The share of EU countries in trade in agri-food products in the last analyzed years was about 74%. Poland's most important partner in agri-food trade is Germany. Their share in exports from Poland in 2023 reached 25.7%. The United Kingdom (now no longer a member of the EU) was second with a share of 8.9%. Further positions were occupied by: Netherlands, France and Italy. The Czech Republic, our second closest neighbor, with a share of 4.7%, ranked sixth in Polish exports of agricultural and food products. On the import side, Germany also had the largest share (19.8% in 2023). However, it should be noted that in the case of this country, the value of imports relative to exports was less than 49% in 2023. Much smaller import shares were recorded for countries such as: Netherlands, Italy, Spain, Norway, Ukraine. It should also be noted that among the 14 countries from where the highest imports of agri-food products were recorded, none of them had a negative trade balance in 2023. The Czech Republic ranked eleventh from the point of view of the value of imports in 2023. The scale of trade between Poland and the Czech Republic was much more balanced, with a slight positive balance in favor of Poland (the ratio of the value of imports to Poland to exports of Poland to the Czech Republic was approximately 84% in 2023). Similar figures have been recorded since 2014.

Detailed data on the turnover of Poland's international trade in agri-food products with the Czech Republic between 2014 and 2023, compared with total turnover data and data on Poland's largest counterparty, are presented in Figure 3–5.

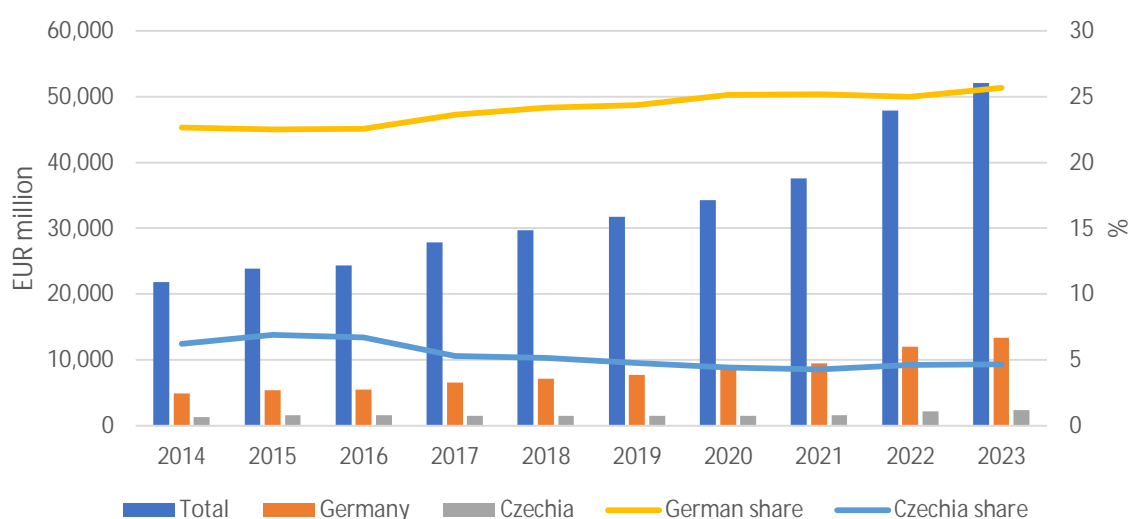


Figure 3. Exports of agri-food products from Poland, taking into account Germany and the Czech Republic and their shares in total exports of these products from Poland from 2014 to 2023 (EUR million, %), own processing based on data from the Ministry of Agriculture and Rural Development (Ministerstwo Rolnictwa i Rozwoju Wsi, 2013, 2014, 2015, 2016, 2017, 2018, 2020, 2021, 2022, 2023)

The value of Poland's agri-food exports has risen by around 140% over 10 years and exports to Germany have increased by 170%. Exports to the Czech Republic also increased during this period, but to a much lesser extent - by around 80%. The data indicate a relatively stable growth in agri-food exports, both overall and to both countries. Significant changes in shares in the structure of Polish exports occurred after 2017. The Czech Republic's share has decreased slightly since that period and stabilized at around 5% and Germany's share has increased from around 23% to around 25%.

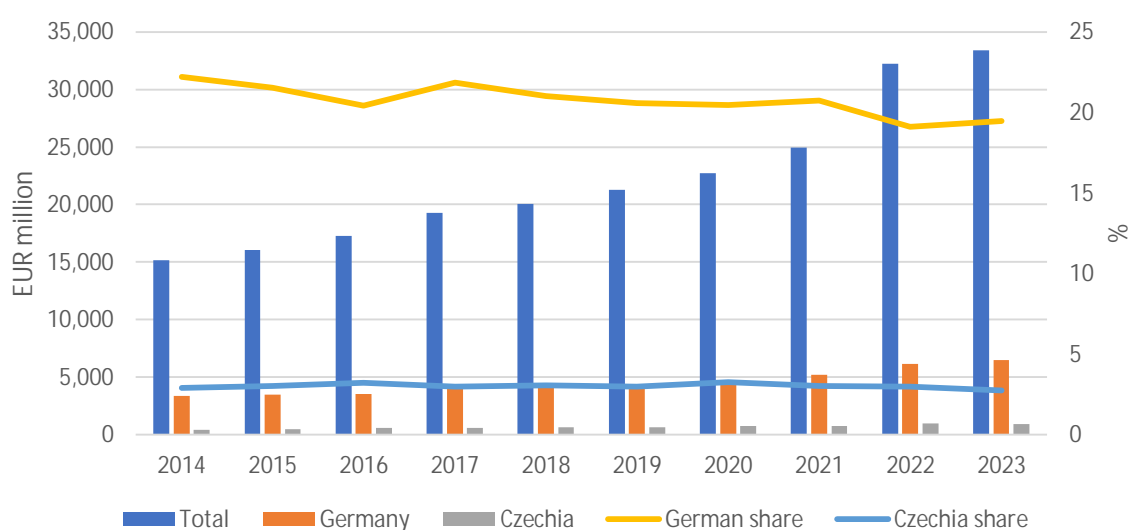


Figure 4. Imports of agri-food products to Poland, taking into account Germany and the Czech Republic and their shares in total imports of these products to Poland from 2014 to 2023 (EUR million, %), own processing based on data from the Ministry of Agriculture and Rural Development (Ministerstwo Rolnictwa i Rozwoju Wsi, 2013, 2014, 2015, 2016, 2017, 2018, 2020, 2021, 2022, 2023)

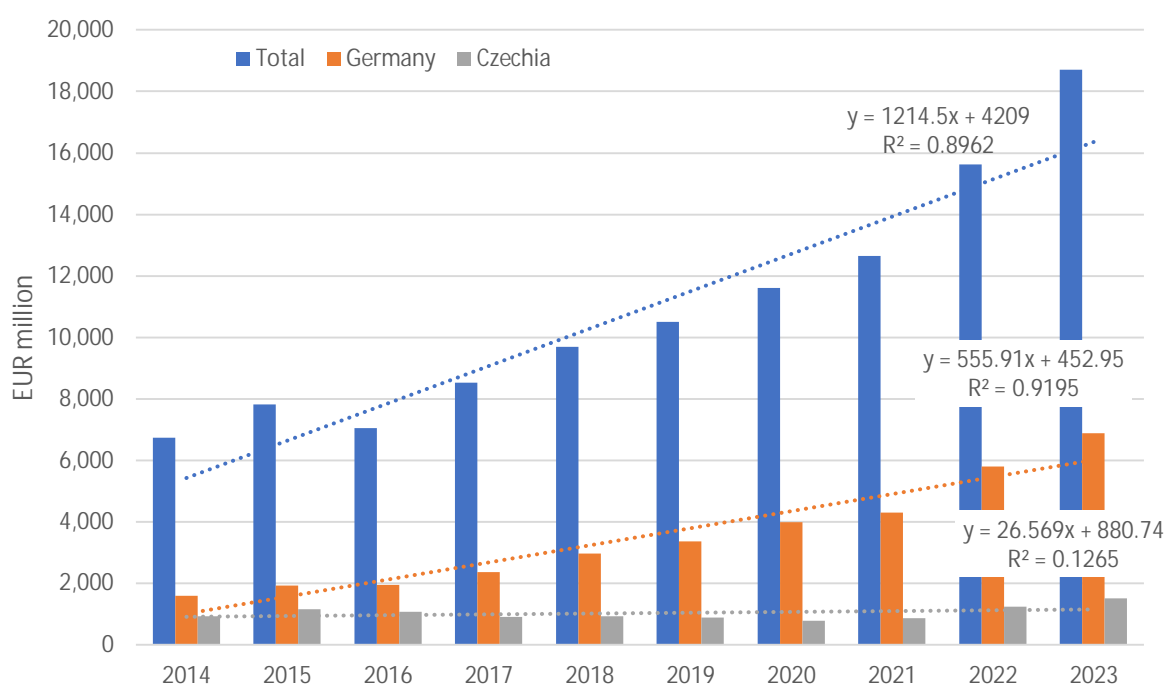


Figure 5. Balance of international trade in agri-food products of Poland including Germany and the Czech Republic from 2014 to 2023 (EUR million), own processing based on data from the Ministry of Agriculture and Rural Development (Ministerstwo Rolnictwa i Rozwoju Wsi, 2013, 2014, 2015, 2016, 2017, 2018, 2020, 2021, 2022, 2023)

Slightly different trends can be observed in the case of data on the volume of imports of agri-food products to Poland (Figure 4). Between 2014 and 2023, imports to Poland increased by around 120%. Imports from Germany increased by around 93.4% and from the Czech Republic, to a slightly greater extent, by around 101%. The Czech Republic's share was fairly stable throughout the period under review, ranging from 2.7% to 3.3%. The share of Poland's largest counterparty, also in the case of imports, declined quite steadily, from 22.2% in 2014 to 19.5% in 2023.

As a result of the changes in international exchange, the positive balance of this exchange increased during the analysis 10 years from EUR 6.7 billion to EUR 18.7 billion, i.e. by over 170% (Figure 5). This means an average annual increase of more than EUR 1.2 billion, with a very good trend line match. A more favorable relationship occurred in the case of Germany (an increase in the balance of more than 4.3 times, an average annual increase of more than 555 million Euros, with very good trend line matching). During this period, the positive balance in trade with the Czech Republic increased by 64.5%, to just over EUR 1.5 billion.

3.2. Analysis of Specific Data on the Main Agri-Food Product Groups

The next data analyzed concerns exports from Poland of the main product groups and apples from Poland to the Czech Republic (Table 1). The largest product group in terms of export value was fresh, chilled and frozen poultry meat and edible offal. Poland is a potentate in poultry production in the Union. Approximately half of its production, which has grown very rapidly in recent years, is exported and Poland ranks first in the

EU in terms of production volume. In 2023, poultry exports from Poland reached €4.1 billion, of which exports to the Czech Republic amounted to €224.4 million. Poultry exports from Poland in value terms have nearly tripled in 10 years and to the Czech Republic doubled. Quantitatively, total exports increased by just over 130% and to the Czech Republic by 29%. These data indicate a significant price increase in poultry exports. This was probably due to the strengthening of Poland's competitive position on foreign markets for this group of products. Data on the share of both volume and value of poultry exports to the Czech market in the total volume of poultry exports from Poland had a downward trend, but their shares were higher than in the case of total value and volume.

The second group in terms of value of exports to the Czech market is dairy products. Their share in the total value of dairy products exported from Poland ranged from 7.04% in 2017 to 8.34% in 2018 and its value increased by 66.5% between 2014 and 2023, with an overall increase of 60.6% in exports of these products from Poland. In value terms, exports of dairy products to the Czech Republic accounted for 7.04% in 2017 to 8.54% in 2016 of the total value of exports of these products. In volume terms, total exports of these products increased by 47.9% and to the Czech Republic by less than 2%, with both the volume and value of exports to this country fluctuating slightly from year to year. There was also a noticeable increase in export prices for this group of products.

Poland also exports significant amounts of pork to the Czech Republic. Compared to 2014 in 2023, exports of this product group increased both in terms of volume and value. Poland's pork exports have been declining in volume, especially in recent years, and in 2023 account for 78% of the 2014 figure. In the case of the Czech Republic, these exports increased by 16.7% and fluctuated slightly during the analyzed period and accounted for 9.82% of the total quantity of pork exports from Poland. In value terms, the value of total pork exports increased by 17% and exports to the Czech Republic by 57.2%. In 2023, the Czech Republic's share in the value of exports of this product group was nearly 14%.

Poland is a significant beef producer and exporter in the EU. The domestic market for these products is small and the majority of beef produced in Poland is exported (approximately 80% of domestic production). Of the total value of beef exports in 2023. EUR 2 231 million, exports to the Czech market amounted to EUR 58.8 million, or 2.64%. Beef exports from Poland in value terms increased by 133, 4% and to the Czech Republic by 118% in the analyzed years. In volume terms, the figures were 31.6% and 43.4% respectively.

Apples are also an important Polish export product. Their export, in comparison to the first years of the analyzed period, decreased and in 2023 accounted for 74.5% of the volume of 2014, while the export of apples to the Czech Republic in this period increased by approx. 19%. In value terms, the figures look much more favorable. The value of total apple exports increased in this period by around 14% and exports to the Czech Republic by 72.5%, while they accounted for just under 3.5% of the value and 3.25 of the volume of Polish apple exports.

Table 1. Exports of selected groups of agri-food products from Poland to the Czech Republic between 2014 and 2023 (thousand tons, mil. EUR), own processing based on data from the Ministry of Agriculture and Rural Development (Ministerstwo Rolnictwa i Rozwoju Wsi, 2013, 2014, 2015, 2016, 2017, 2018, 2020, 2021, 2022, 2023)

Specification	years									
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
BEEF MEAT, FRESH, CHILLED OR FROZEN (CN 0201, 0202)										
Quantity										
Total	308.85	369.97	363.06	406.59	395.85	382.15	380.64	374.92	364.26	406.58
Czechia	7.74	8.51	9.26	10.51	11.84	8.37	9.15	11.74	11.14	11.10
Value										
Total	955.92	1,211.55	1,176.33	1,404.57	1,478.35	1,397.91	1,388.02	1,596.83	2,089.30	2,230.79
Czechia	27.00	30.30	32.73	38.26	41.66	33.30	36.82	51.75	61.37	58.85
MEAT AND EDIBLE OFFAL OF POULTRY, FRESH, CHILLED OR FROZEN (CN 0207)										
Quantity										
Total	714.26	849.57	1,025.10	1,156.32	1,324.61	1,460.85	1,494.58	1,481.53	1,592.26	1,646.24
Czechia	63.78	68.14	74.91	78.22	82.21	79.91	83.40	70.70	73.31	82.32
Value										
Total	1,370.43	1,655.07	1,783.58	2,002.47	2,383.77	2,615.18	2,359.05	2,731.95	4,296.89	4,092.41
Czechia	112.66	122.91	133.56	143.42	169.17	159.58	144.17	149.31	215.68	224.36
PORK MEAT, FRESH, CHILLED OR FROZEN (CN 0203)										
Quantity										
Total	383.36	407.88	437.02	484.48	509.10	448.01	394.17	413.49	352.55	299.03
Czechia	25.16	31.58	31.23	28.56	31.43	28.11	29.02	27.09	30.18	29.36
Value										
Total	704.46	703.15	796.32	974.83	874.68	858.77	779.04	756.61	815.60	823.97
Czechia	73.14	78.24	79.64	76.72	79.87	80.18	80.40	68.14	97.82	114.96
DAIRY PRODUCTS (CN 0401 - 0406)										
Quantity										
Total	1,153.12	1,272.82	1,309.75	1,412.26	1,497.81	1,625.75	1,649.48	1,704.28	1,695.75	1,697.24
Czechia	57.39	61.24	60.36	53.05	58.35	60.16	53.67	53.89	56.98	58.46
Value										
Total	1,818.18	1,548.35	1,478.43	2,032.87	2,081.04	2,095.41	2,088.78	2,350.52	3,303.50	2,920.86
Czechia	130.07	115.14	125.95	143.20	173.66	163.23	147.49	168.37	238.39	216.63
APPLES (CN 080810)										
Quantity										
Total	1,096.05	945.87	1,092.14	1,037.46	810.39	990.10	659.69	939.42	745.92	816.90
Czechia	22.29	67.30	40.08	31.58	27.64	27.80	26.76	30.12	23.81	26.52
Value										
Total	351.59	299.49	316.82	351.56	334.86	333.05	303.09	358.99	300.71	402.02
Czechia	8.10	24.81	14.06	14.64	15.52	11.67	16.52	14.11	10.76	13.97

4. Discussion and Conclusions

An analysis of trade in agri-food products between Poland and the Czech Republic shows a dynamic increase in trade despite the existence of so-called soft non-tariff barriers. This is because their negative effects were borne only by individual companies, which, according to the Czech authorities, offered non-compliant products. Between 2014 and 2023, Poland maintained its position as one of the main food suppliers to the Czech Republic,

which confirms the growing competitiveness of the Polish agri-food sector. Particularly noticeable is the increase in exports of poultry meat, dairy products and pork, which are key elements of this exchange.

The introduction of stricter administrative regulations by the Czech Republic after 2016 affected the dynamics of Polish exports, but did not hinder their growth. Moreover, Poland has shown great flexibility and adaptability, successfully adjusting to new market requirements. Integration with the EU market and effective use of comparative advantages in terms of production costs were important factors in maintaining competitiveness.

On the other hand, the trade structure indicates some challenges, including the concentration of exports in specific product segments and vulnerability to regulatory changes in the Czech Republic. Further research is needed on the diversification of the export mix and strategies to minimize the risks arising from potential future trade restrictions.

In conclusion, it can be stated that trade in agri-food products between Poland and the Czech Republic has been steadily and gradually developing to the benefit of both countries and has had a balanced character, with Poland achieving a slight positive balance in this exchange in each of the years.

An analysis of the price data for poultry exports, but also for other animal products, in the first years after Poland's accession to the EU indicates that initially this competition was mainly of a price nature. Nowadays, product quality and brand play a greater role. Among the most important findings are:

- Poland has maintained a strong position as an exporter of agri-food products to the Czech Republic, despite regulatory and administrative changes;
- the highest growth in exports was recorded in the poultry meat, dairy products and pork sector;
- Polish producers are successfully adapting to the requirements of the Czech market, which indicates high competitive flexibility;
- there is a need to further diversify exports and explore new product segments to minimise regulatory risks.

Implications and further research directions include:

- an analysis of the mechanisms that have allowed Polish exporters to remain competitive despite the administrative barriers introduced by the Czech Republic;
- an assessment of the role of EU trade policy and regulations on trade between Poland and the Czech Republic and their long-term impact;
- an examination of potential new product categories that could increase the stability of agri-food trade;
- an analysis of the impact of global factors such as climate change, customs policy or the COVID-19 pandemic on agri-food trade.

The authors recognize that the study is based on historical data, which may not reflect current market developments in real time. Moreover, it focuses on economic aspects and does not include a detailed assessment of the legal aspects of non-tariff barriers. The study also

does not take into account the individual strategies of Polish export companies and their approach to the Czech market.

In conclusion, despite the existing challenges, Poland has consistently strengthened its position on the Czech market for agri-food products, which confirms the effectiveness of the domestic agricultural sector and food industry. However, further diversification of exports and analysis of long-term regulatory changes may contribute to even greater stability of this trade exchange.

Conflict of interest: none

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AI-Powered Value Proposition: Revolutionizing Customer Engagement

Petra PÁRTLOVÁ and Kristína VYŠÍNOVÁ*

Czech University of Life Sciences Prague, Prague, Czech Republic; partlova@pef.czu.cz; vysinova@pef.czu.cz

* Corresponding author: vysinova@pef.czu.cz

Abstract: This study explores the integration of artificial intelligence (AI) into the Value Proposition Canvas (VPC) model, emphasizing its impact on business processes, customer need identification, and company performance. It examines AI applications across different VPC stages, focusing on technologies such as natural language processing (NLP), machine learning (ML), and generative AI. These technologies enhance customer insights, allowing businesses to develop highly personalized value propositions (VPs) and improve market responsiveness. A case study of a luxury resort illustrates how AI-driven analytics refine decision-making, optimize customer engagement, and increase the accuracy of VPs. The findings suggest that AI integration leads to improved personalization, greater strategic adaptability, and higher operational efficiency. Furthermore, AI adoption strengthens automation, streamlines data-driven optimization, and enhances customer-centric approaches, ultimately driving competitive advantage. By leveraging AI, businesses can improve targeting, enhance strategic planning, and create more efficient and responsive VPs. The study provides practical recommendations for companies seeking to integrate AI into their VP strategies, ensuring long-term success in an increasingly digital and competitive marketplace.

Keywords: value proposition canvas; artificial intelligence; customer needs; personalization; strategic planning; business model innovation

JEL Classification: M31; O32; L86

1. Introduction

Artificial intelligence (AI) has emerged as a key driver of innovation across industries, particularly in business and marketing. Its ability to process vast amounts of data and uncover hidden patterns—such as buying behavior, interactions, and customer needs—enables companies to optimize value propositions (VPs) and respond more effectively to market demands (Chandra et al., 2023; Muth & Nufer, 2024). One strategic tool that stands to benefit significantly from AI's analytical capabilities is the Value Proposition Canvas (VPC), which helps businesses systematically structure and communicate VPs for customers (Li et al., 2024). However, traditional approaches to gathering and analyzing customer insights often suffer from inefficiencies and subjectivity. AI addresses these challenges by rapidly processing large datasets, providing deeper and more objective insights into customer behavior (Kaleel & Alomari, 2024). Recent studies emphasize AI's growing role in business

model innovation, particularly through ML applications in Value Proposition Design (VPD), which enable managers to refine and develop strategic VPs with greater precision (Rodríguez & Calvario, 2024). The integration of AI into such tools is becoming essential for maintaining competitiveness in dynamic market environments (Rodríguez & Calvario, 2024).

Despite its potential, the intersection of AI and the VPC remains underexplored. While existing research primarily examines AI's role in marketing, its integration into comprehensive strategic tools like the VPC has received limited attention (Chandra et al., 2023). This study seeks to bridge this gap by analyzing the opportunities and challenges of AI-enhanced VPC frameworks. It contributes to the theoretical discourse by demonstrating how AI can reshape traditional strategic management tools, fostering business model innovation and improving customer value creation. These insights lay the groundwork for further research and offer practical implications for businesses navigating an increasingly AI-driven market.

The study aims to examine how AI integration into the VPC enhances customer need identification and VP optimization, focusing on three research questions:

- RQ1: What specific AI technologies and tools are most appropriate for each stage of the VPC model and how can they improve the efficiency of these processes?
- RQ2: What are the main benefits of integrating AI into the VPC model in terms of improving the accuracy of identifying customer needs, personalization of VPs, and efficiency of decision-making processes?
- RQ3: What specific metrics can be used to measure the impact of integrating AI into the VPC on business performance and customer satisfaction?

2. Literature Review

Perifanis and Kitsios (2023) state that AI is transforming business models and strategies, with technologies such as (ML), deep learning (DL), and natural language processing (NLP) playing a crucial role in data analysis and decision-making. Organizations leveraging AI report significant improvements in performance and innovation. Kulkov et al. (2024) argue that integrating AI into the VPC enables more precise analysis of customer behavior and market trends, leading to better alignment of products with customer needs. AI also enhances firms' ability to respond to market changes in real time, supporting offer personalization and increasing customer satisfaction (Farayola et al., 2023). Shaik et al. (2024) highlight that AI also presents challenges, particularly concerning data protection and the diminishing role of human interaction in services. Automation raises concerns about job displacement and reduced oversight, which, according to Ofodile et al. (2023), requires a balanced approach. Kulkov et al. (2024) emphasize the need for ethical AI development, including transparency, consumer protection, and regulatory compliance. While AI improves customer insights and personalization, Farayola et al. (2023) stress the necessity of adhering to data protection standards. Future research should focus on best practices for AI integration, its long-term impact on business, and alignment with evolving regulatory frameworks.

3. Methodology

The proposed methodology provides a structured approach to designing VPs for a holiday resort, aiming to create a competitive, customer-centric service framework. Key criteria include customer data, resort operations, and sustainability goals. AI tools supported the development of the VPC and Business Model Canvas (BMC), refining insights and strategies, while DALL-E generated concept visualizations. Between March and June 2024, only internal data and detailed customer profiles from resort management were used, without external surveys or AI-generated data. This methodology consists of five main steps:

1. *Initial market analysis and segmentation*: The first phase involves: (1) industry research, identifying key trends and competitors; (2) defining offered products and services with unique attributes; and (3) profiling target customers based on demographic, psychographic, and behavioral characteristics.
2. *Formulation of VP*: This step defines the resort's (1) identity and mission, (2) key projects and initiatives, and (3) approach to addressing customer needs.
3. *In-depth analysis of the target group*: A detailed analysis covers: (1) demographic profiling, (2) psychographic and lifestyle characteristics, (3) geographic factors affecting demand, and (4) behavioral patterns in service selection and booking.
4. *Development and optimization of VP*: Key tasks include: (1) identifying customer needs (jobs-to-be-done), (2) analyzing pain points and expected gains, (3) proposing tailored products and services, and (4) integrating value-adding elements.
5. *Implementation and continuous evaluation*: The final stage focuses on: (1) executing proposed strategies with service quality emphasis, (2) systematically monitoring results via customer feedback and operational data, and (3) iteratively optimizing based on findings.

4. Results

4.1. Introduction: Resort Overview

For confidentiality reasons, the name and exact location of the holiday resort will not be disclosed in this section. Situated by a lake, the resort offers a diverse range of experiences, from relaxation and outdoor activities to special events. Accommodation prioritizes guest comfort and privacy, featuring various suite types designed with modern aesthetics and quality materials. The gourmet restaurant, offering a sunset view over the lake, is a key attraction, further enhanced by a newly opened café specializing in French pastries, appealing to a discerning clientele.

The resort's location supports year-round sports activities, including cycling, hiking, and winter sports. A standout architectural feature is the pier extending into the lake, serving as both an aesthetic element and a venue for weddings and celebrations.

Active social media communication keeps guests informed about current offers and events, facilitating stay planning. The combination of natural beauty, premium services, and well-organized events strengthens the resort's market position, making it a sought-after destination for holidays and major social gatherings.

4.2. Step 1: Initial PROMPT for Creating the VPC

The first step provided essential information for adapting the VPC to the company's specific conditions. Research identified three key areas:

1. **Business sector context:** A detailed industry overview, including key trends and challenges, provided the necessary background for developing a relevant VP. Understanding the competitive landscape helped frame the company's opportunities and constraints.
2. **Product/Service specification:** Beyond basic functions, emphasizing unique features and competitive advantages was crucial. This clarity enabled precise identification of customer needs and how the product addresses them, forming a foundation for the VPC.
3. **Target group definition:** Customer demographics, behaviors, needs, and motivations played a pivotal role. Understanding their pain points and decision-making processes was essential for designing an effective VP and tailored strategies.

These insights formed the basis for the subsequent development of a well-structured VPC, ensuring alignment with both market dynamics and customer expectations.

4.3. Step 2: Detailed Description of the VP

This step defined the company's identity, offer, and approach to addressing visitor needs and challenges.

1. *Who are we?* The company operates in the premium services sector, combining first-class gastronomy with an exclusive lakeside setting. Its main facility, a gourmet restaurant, leverages this unique location to enhance the luxury experience.
2. *What do we do?* A key objective is the protection of the pier, which serves both as a restaurant access point and a public space. However, issues such as cycling, skating, fires, fishing, and jumping into the water pose safety and property risks. In response, the company is developing an innovative product to educate visitors on conduct rules in a respectful and non-invasive manner. This approach preserves the pier's exclusivity and safety while promoting responsible behavior.

This phase was crucial in shaping the next stages of the VPC process, where specific strategies and recommendations will be developed.

4.4. Step 3: Defining the Target Group

This step focused on detailed profiling of the target group, which was essential for shaping an effective VP and marketing strategies.

- *Demographics characteristics:* The primary target group consists of mature adults (30-65) from middle to upper-income brackets, who prioritize high-quality services. Most hold a college degree, reflecting their appreciation for comprehensive and premium offerings.
- *Psychographics characteristics:* These clients value luxury, sustainability, and unique experiences, favoring locally sourced ingredients and ethically responsible products.

They are interested in gastronomy, travel, nature, outdoor activities, culture, and the arts, with sustainability and ethical principles being key in their decision-making.

- *Geographics characteristics:* The main clientele comes from the Czech Republic and border regions of Germany and Austria (Bavaria, Upper Austria), strategically important due to easy accessibility. Most clients reside in urban or suburban areas with strong transport infrastructure.
- *Behavioral characteristics:* The target group prefers premium services, values quality, sustainability, and ethical standards, and invests accordingly. Their consumption behavior includes online bookings, review analysis, and a preference for dining experiences with minimal environmental impact.

This detailed profile provides a solid foundation for creating a VP tailored to client needs, ensuring strategic alignment with their preferences, enhancing satisfaction and experience.

4.5. Synergistic Model of VP and Customer Profile

The VPC model (see Figure 1) provides a comprehensive perspective on both the VP and the detailed customer profile, capturing the needs of both exclusive restaurant guests and public pier users. The model effectively integrates education, sustainability, and community engagement, which has proven essential for maximizing satisfaction among all user groups.

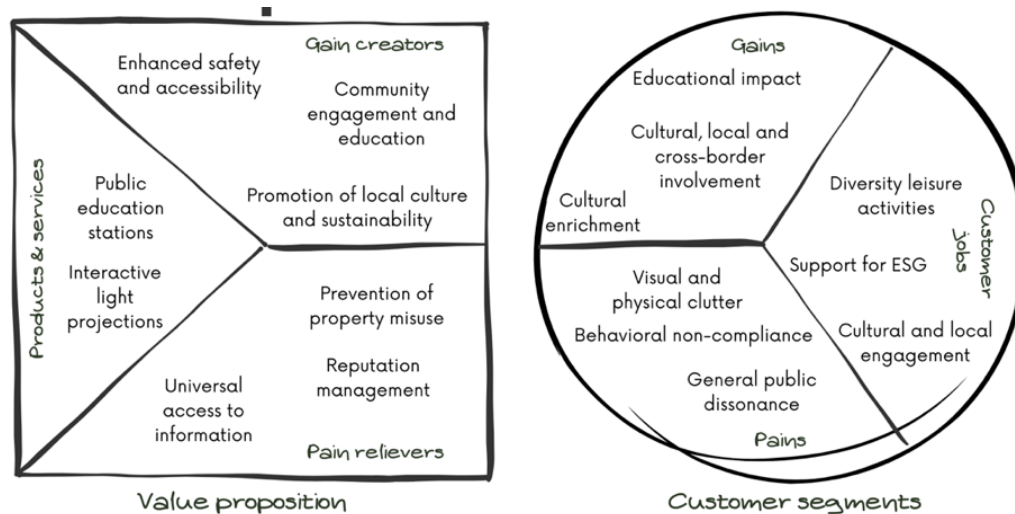


Figure 1. Synergistic model of value proposition and customer

A key component of the VP is the introduction of innovative products and services that facilitate clear and aesthetically appealing communication of rules of conduct. These tools aim to promote responsible behavior while preserving the pier's exclusivity and ensuring a harmonious environment. The VPC model also carefully reflects the aspirations, challenges, and expectations of the target audience, particularly their preferences for luxury, sustainability, and unique experiences.

In addition, the model illustrates how the needs of different visitor segments—from demanding restaurant guests to casual pier users—can be aligned through high-quality services that uphold both exclusivity and accessibility. This balance is achieved by

implementing strategies that encourage sustainable and responsible behavior, ensuring that the resort maintains its premium positioning while remaining open to the wider public.

By integrating luxury, sustainability, and community responsibility, the model presents an innovative approach to managing an exclusive facility within a publicly accessible space. It successfully addresses operational challenges while strengthening the resort's attractiveness and competitiveness, demonstrating how a well-structured VP can enhance the overall guest experience and long-term business sustainability.

4.6. Integrated Model of Strategic Business and VP

Based on a thorough VPC analysis, an additional BMC has been developed (see Figure 2). This model provides a structured, holistic view of the key components of project success by effectively interlinking VPs, target customers, and operational processes. A key advantage of this model is its role as a comprehensive tool for strategic management and planning. The analysis highlights its ability to integrate several critical areas:

1. *Educational and information tools*: Innovative methods ensure non-intrusive communication of rules, raising visitor awareness while preserving their experience. This is achieved through key resources such as digital totems and light projections, which serve as interactive technology for conveying rules and sustainability information.
2. *Sustainability and environmental protection*: The model promotes responsible pier management, encouraging visitor engagement in ecosystem conservation and long-term project sustainability. This is supported by partnerships with sustainability brands and the promotion of eco-friendly practices through VPs.
3. *Attractiveness and safety*: It balances increasing the pier's appeal with ensuring user safety, addressing the needs of both restaurant guests and the public. This is reflected in the enhanced safety and accessibility VP, which uses technology to improve visitor safety and information access.

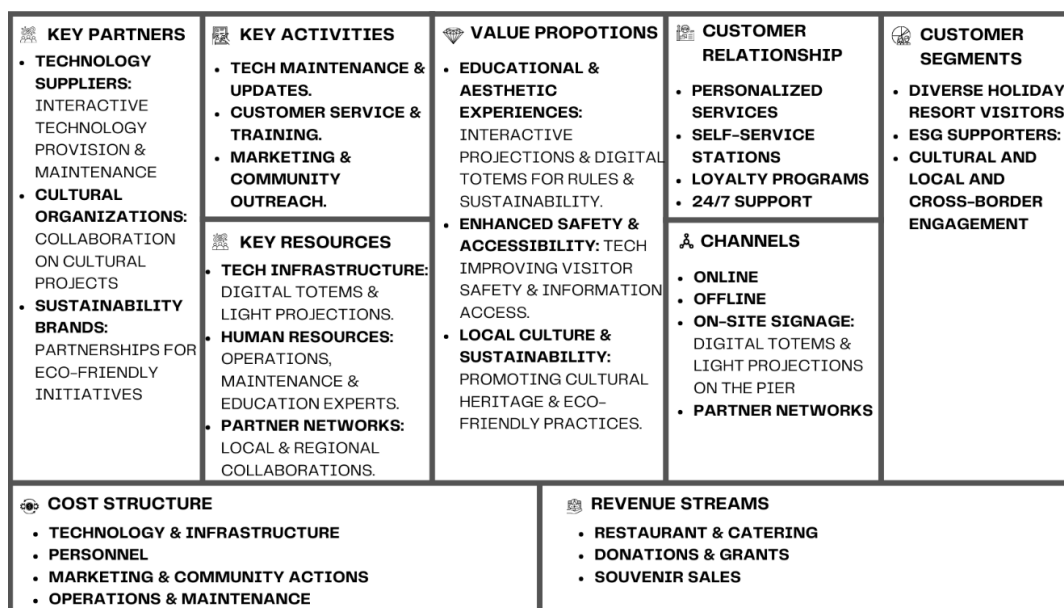


Figure 2. Integrated model of strategic business and value proposition.

The integrated model incorporates key partners like technology suppliers and cultural organizations, focusing on technology maintenance, customer service, and marketing. It addresses diverse customer segments, including holiday resort visitors and ESG supporters, through various channels such as online platforms and on-site signage. Revenue streams are diversified, including restaurant income and donations for sustainable tourism. The cost structure covers technology, personnel, and marketing investments. This model effectively identifies growth opportunities and supports long-term planning, accommodating diverse target groups while maintaining a coherent strategy, fostering a sustainable and inclusive approach to project management.

4.7. PASTOR Framework: Innovative Approach to Creating Content for Landing Page

The PASTOR framework, applied through AI, enables the creation of engaging and structured content for a website. This approach ensures clear communication of the VP, effectively targeting visitors by addressing their needs, concerns, and expectations. The framework consists of six key elements:

1. *Problem:* A well-crafted headline like *"Looking for a unique dining experience?"* immediately captures attention. The accompanying subtitle and content highlight the challenge of combining exclusivity, sustainability, and accessibility.
2. *Amplify:* This section emphasizes the common contradiction between luxury and restrictions. A phrase like *"A luxurious environment should be synonymous with freedom and relaxation"* resonates with visitor expectations.
3. *Solution:* The project's innovative approach to sustainable luxury is presented through elements such as interactive light projections and digital totems, enhancing the visitor experience while promoting responsible behavior.
4. *Testimonials:* Authentic guest experiences reinforce credibility, demonstrating the real impact of the proposed solutions and strengthening trust in the brand.
5. *Objection Handling:* Addressing potential visitor concerns, such as whether luxury and sustainability can coexist, proactively removes barriers to engagement and reassures potential customers.
6. *Response:* The final step encourages visitors to actively engage, integrating booking options with a sustainability appeal, motivating them to be part of an environmentally responsible experience.

4.8. Design Proposal: Information Elements for an Exclusive Resort with a Pier

The research led to the creation of two key visual designs that blend functionality and aesthetics while maintaining the luxurious character of the resort. These concepts were visualized using DALL-E to generate realistic representations.

Interactive Light Projections on the Pier

The design (see Figure 3) integrates modern technology into the pier's natural setting without compromising its ambiance. Key elements include: (1) subtle interactive light

projections activated by movement, (2) strategic placement for maximum visibility, (3) an elegant, unobtrusive design, and (4) clear communication of safety messages and rules of conduct.



Figure 3. Elegant information integration on the pier (Note: Prompt: A modern waterfront at dusk by a peaceful lake in a protected natural area. A hexagonal wooden building with minimalist architecture glows softly at the center. A wide wooden pier extends over calm water, featuring warm pathway lights, family-friendly icons, and interactive light projections activated by movement. Discreet digital screens display safety messages. Elegant sailboats and motorboats are docked nearby, with low-rise modern buildings blending into the landscape. The scene is framed by green grass, bushes, and tall pine trees under a softly glowing sunset sky.)

Digital Totem at the Entrance to the Restaurant

The digital totem (see Figure 4) is designed to complement the resort's sophisticated aesthetic with the following features: (1) a slim, space-efficient shape, (2) premium materials (brushed metal, dark wood) for a refined appearance, (3) an interactive touch screen with an intuitive interface, (4) engaging content focused on safety and visitor guidance, and (5) strategic placement at the entrance for high visibility.



Figure 4. Modern information totem (Note: Prompt: A modern outdoor information totem seamlessly blending with a sophisticated setting. It features a slim vertical design, combining brushed metal and dark wood for an elegant look. The interactive touch screen displays safety information with an intuitive interface. Positioned at the entrance of a modern restaurant, it ensures high visibility. The background showcases minimalist architecture with large glass windows, while soft ambient lighting enhances its sleek and functional design.)

5. Discussion

- RQ1: What specific AI technologies and tools are most appropriate for each stage of the VPC model and how can they improve the efficiency of these processes?

Findings indicate that specific AI technologies enhance each stage of the VPC, significantly improving efficiency and accuracy. For customer need identification, NLP enables efficient analysis of large textual datasets, such as customer reviews and social media posts, providing deeper insights into jobs-to-be-done, pain points, and expected gains (Si, 2020; Obiki-Osafiele et al., 2024). In VPD, ML algorithms facilitate advanced customer segmentation and personalized VPs, increasing the relevance of offerings across market segments (Khan et al., 2024; Malikireddy, 2024). For communication optimization, generative AI models, particularly GPT-based technologies, automate the creation of marketing content tailored to customer needs, significantly improving campaign effectiveness (Toteva, 2023; Sujeet Dutta, 2024). For data visualization and presentation, AI-driven visualization tools create interactive and dynamic representations, aiding in the interpretation of complex data and supporting faster decision-making (Uchihira et al., 2024). From a cost perspective, generative AI platforms, including ChatGPT, typically operate on a freemium or subscription basis, with entry-level plans starting at a few dozen dollars per month. This study utilized the paid version of ChatGPT (GPT-4) for its advanced reasoning and language capabilities, ensuring higher accuracy in automated content generation and analytical tasks.

- RQ2: What are the main benefits of integrating AI into the VPC model in terms of improving the accuracy of identifying customer needs, personalization of VPs, and efficiency of decision-making processes?

AI enhances customer need identification by enabling precise analysis of large datasets from multiple sources. ML, predictive analytics, and NLP help uncover behavioral patterns and customer preferences with unprecedented accuracy (Rini et al., 2024). These technologies facilitate personalized content and product recommendations, further supported by research confirming their impact (Mekkawi, 2024). The personalization of VPs is strengthened through ML-driven customer segmentation, allowing for tailored offerings. AI-driven personalization in e-commerce significantly improves the customer experience (Thakur et al., 2024), while hyper-personalization using AI and edge computing reduces latency in customer interactions by up to 70% and increases conversion rates by approximately 30% (Islam et al., 2024). Finally, AI-driven automation accelerates data collection and analysis, optimizing VP development. Businesses implementing digital tools report higher revenue growth and improved operational efficiency (Hakim, 2025), while AI remains a key driver of digital transformation, reinforcing global competitiveness (Makar, 2023).

- RQ3: What specific metrics can be used to measure the impact of integrating AI into the VPC on business performance and customer satisfaction?

Customer satisfaction is primarily measured through Net Promoter Score (NPS), Customer Satisfaction Score (CSAT), and Retention Rate. While NPS is widely used, its

validity remains debated (Diliasari & Sulistiadi, 2024). CSAT, closely linked to patient enablement, also proves relevant in specialized industries such as healthcare (Ämmälä & Taimela, 2024). Performance indicators (KPIs) include conversion rate, average transaction value, and customer acquisition cost (CAC). Improving NPS directly influences conversion rates (Iroth & Sinaga, 2024), while research confirms the connection between transaction value and overall NPS scores, highlighting the impact of customer satisfaction on business performance (Pinar et al., 2024). AI adoption metrics such as adoption rate, implementation time, and return on investment (ROI) play a crucial role in assessing AI's effectiveness. AI integration positively influences macro-level metrics like ROI and operational KPIs, including employee and customer satisfaction (Berest, 2024), with rapid implementation being key to maximizing efficiency and customer experience (Katragadda, 2024).

These findings emphasize the need to combine traditional customer satisfaction metrics with AI-driven performance evaluation to assess AI's impact on the VPC. This holistic approach helps organizations adapt to customer needs in a digitally transforming market. However, the rapid evolution of AI may affect metric relevance over time, and their effectiveness depends on industry specifics and company size. Future research should track long-term applicability and develop new methodologies to capture AI's increasingly complex impact on business performance and customer experience.

6. Conclusions

This study confirms that integrating AI into the VPC process modernizes corporate strategies, improving customer need identification and enabling highly personalized VPs. Advanced tools like machine learning and natural language processing enhance adaptability to market changes and create new opportunities for product and service development. While based on a single case study, the findings are adaptable to other business environments, with cross-platform comparisons offering further validation.

Despite its benefits, AI adoption requires addressing challenges such as investment costs, infrastructure, and employee training through a systemic, long-term approach. Evaluating AI's impact on the VPC process necessitates combining traditional and emerging metrics, including key performance indicators and customer satisfaction. Future research should explore AI's long-term effects across industries and refine assessment metrics. Companies effectively leveraging AI in VPC processes will be better positioned to navigate market dynamics and sustain customer value in an evolving digital landscape.

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Conflict of interest: none

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Batch Processing Problem – Case Study

Jan PELIKÁN

University of economics Prague, Prague, Czech Republic; pelikan@vse.cz

Abstract: The article deals with the problem of charging electric vehicles, specifically scheduling of these vehicles at charging stations. The problem is qualified as a batch processing problem on several processors, where the processor is a charging station and the batch is an electric vehicle with a charging time requirement. Two types of mathematical models are proposed, the first maximizes the number of vehicles that could be included in the charging schedule, and the second model requires charging of all vehicles, with the possibility that for some, if necessary, the charging time will be reduced. The models are verified on an illustrative example.

Keywords: batch processing; batch scheduling; integer programming

JEL Classification: C44

1. Introduction

Batch processing problem is a task containing a set of n batches to be processed on K machine processors. Here it will be independent batches without the possibility of interrupting the processing with a given processing time, with the fact that they can be processed on any machine. Machines are independent simultaneous processors. The goal is to assign batches to machines and schedule them.

The batch processing problem exists in various modifications, an overview of them can be found in (Blazewicz et al., 1997) and (Leung, 2004), where there is also the form of various limiting conditions for batch processing and the classification of these tasks is given here. An example case study can be found in (Pelikán, 2011).

2. Electric Vehicle Charging Problem

The subject of the article is the problem of scheduling electric vehicles at charging stations. Charging takes place at charging stations and this process can take from tens of minutes to hours depending on the type of charging stations and the degree of discharge of the cars. We will solve this problem at non-public stations, such as parking garages or corporate parking place, as well as closed group of vehicles.

Let us have n vehicles that require charging in a certain time interval when the driver is not using the vehicle (vehicles are in a business or parks in a reserved parking place). Its charging schedule is determined by the required charging time. The number of charging stations is given, they may also differ in charging speed. It is necessary to assign vehicles to charging stations to determine the start time of charging.

The result of the optimization is the assignment of vehicles to charging stations and the start time of charging. The following models will also solve the case where vehicle time

windows, charging requirements, and charging station capacities are such that there is no solution to this task. In that case, two solutions are proposed, the first admits the possibility that not all vehicles need to be charged (so some will be excluded from charging) and the second solution, in which all vehicles will be charged, but for some the time requirement for charging will be shortened, so they will be charged but for a shorter time than required (i.e. with a reduction of the required charging time).

3. Model with Maximum Number of Charging Vehicles (Model A)

The model does not assume that the vehicles requesting charging with their requirements for charging time and the time window for charging will be such that all vehicles can be charged for a given capacity of charging stations. If the capacity of the stations is sufficient, the model will propose a charging time schedule that includes all vehicles, otherwise it will include only a part of them and the largest number in the charging schedule.

We will use the following information about the vehicles and charging stations (parameters of the model A):

- n the number of vehicles;
- K the number of charging stations;
- d_{ik} the required charging time of the vehicle i if it is charged at station k . It is derived from energy requirement (kWh) and charging speed of station, the actual charging time depends on which station the vehicle will be charged at. Each vehicle is only charged at one of the k stations.
- $\langle t_i^0, t_i^1 \rangle$ the time window of the vehicle i in which charging must be carried out;
- M is a large number.

Variables of the model:

- x_{ij} is binary variable, it is one if vehicle i is charged before vehicle j (not necessary immediately). It should be noted, however, this variable has different meaning than the same variable in traveling salesmen problem;
- y_{ik} is binary, value 1 means that vehicle i is charged at station k ;
- $t_i \geq 0$ is time in which the charging of the vehicle i is started;
- z_i is a binary variable, it is one if vehicle i is charged at some station, otherwise it is zero.

Model A:

$$\sum_{i=1}^n z_i \rightarrow \max \quad (1)$$

$$x_{ij} + x_{ji} = 1, \quad \forall i < j, \quad (2)$$

$$u_i + 1 - M(1 - x_{ij}) \leq u_j, \quad \forall i \neq j, \quad (3)$$

$$\sum_{k=1}^K y_{ik} = z_i, \quad \forall i \quad (4)$$

$$t_i + d_{ik} - M(3 - x_{ij} - y_{ik} - y_{jk}) \leq t_j, \quad \forall i \neq j, \quad \forall k \quad (5)$$

$$t_i^0 \leq t_i + \sum_{k=1}^K d_{ik} y_{ik} \leq t_i^1, \quad \forall i \quad (6)$$

The objective function (1) represents the number of charged vehicles, it will be maximized. Condition (2) ensures that either vehicle i is charged before the vehicle j ($x_{ij} = 1$) or the vehicle j is charged before the vehicle i ($x_{ji} = 1$). However, condition (2) needs to be supplemented by condition (3), which prevents cyclic order of vehicles. It is an anti-cyclical condition similar to the traveling salesman problem. Conditions (2) and (3) generate the order of vehicles in which they are charged.

The time condition (5) ensures that the start time of charging of the vehicle j must be greater than the start time of charging the vehicle i plus the charging time, i.e. the start time of the charging of the vehicle j must follow the completion of the charging of the previous vehicle i . But this only applies if the i vehicle precedes the j vehicle ($x_{ij} = 1$) and the vehicle i is assigned to the same station as the vehicle j ($y_{ik} = y_{jk} = 1$). Thus, if all three binary variables y_{ik}, y_{jk} and x_{ij} are one, their sum is 3. If this sum is less than 3, then all these conditions are not met and a large number M is subtracted from the left-hand side of (5) thanks to therefore, condition (5) does not affect on the value t_j on the right-hand side of the inequality (5).

Condition (6) is the condition of the time window of vehicle i , which ensures that the charging of the vehicle i takes place within the time window $< t_i^0, t_i^1 >$.

Condition (4) determines the value of the binary variable z_i which is equal to one if the vehicle i is charged at any of the charging stations, otherwise it is equal to zero. At the same time, it prevents the vehicle from being charged on multiple stations.

4. Model with the Condition of Charging All Vehicles (Model B and C)

All vehicles will be charged in these models. If the capacities of the stations would not allow it, the model allows for a reduction in charging requirements. The reduction in the charging time d_{ik} of vehicle i at station k will be reduced to $r_i d_{ik}$, where the variable $r_i \in (0,1 >$ is a variable of the model. If the reduction r_i is one, the requirement d_{ik} will not be reduced, otherwise these reductions will have to be brought as close as possible to the value one. In model B, we will maximize $Rmin$, the variable with the smallest value of these reductions r_i . We then use this optimum value in model C, where the problem is to find the r_i in such a way that the requirements of the vehicles are achieved as much as possible and at the same time the capacity of the charging stations is used to the maximum.

The solution proceeds in two phases: in the first phase (model B) we obtain the maximum value of $Rmin$ for which it is possible to ensure the charging of all vehicles, in the second phase we maximize the reductions (as the sum of r_i) in order to achieve higher values of r_i .

Model B contains the following additional variables compared to model A:

- $r_i \in (0,1)$ reduction in vehicle demand i ;
- $Rmin \geq 0$ maximum minimum reductions r_i ;
- $dr_i \geq 0$ reduced vehicle charging time of the vehicle i .

The constraints define the order of vehicles are the same in model A (2)-(3) and in the model B (8), (9) and in the model C (16), (17). Unlike the model A equation (10) in model B and (18) in model C requires charging all vehicles. Furthermore, conditions (11), (12) are a modification of conditions (5), (6) in the model A where instead of the charging requirement d_{ik} , a reduced requirement dr_i is inserted in these inequalities.

Inequality (13) of the model B defines the reduced charging requirement dr_i , is the same in the model C (21).

Model C contains the parameter $Rmin$, which is the optimal value of the object function of the model B, this parameter ensures the minimum of all reductions r_i in the inequality (22). The sum of the reductions r_i is the objective function of the model C.

Model B:

$$Rmin \rightarrow \max \quad (7)$$

$$x_{ij} + x_{ji} = 1 \quad \forall i < j, \quad (8)$$

$$u_i + 1 - M(1 - x_{ij}) \leq u_j, \quad \forall i \neq j, \quad (9)$$

$$\sum_{k=1}^K y_{ik} = 1, \quad \forall i \quad (10)$$

$$t_i + dr_i - M(3 - x_{ij} - y_{ik} - y_{jk}) \leq t_j, \quad \forall i \neq j, \quad \forall k \quad (11)$$

$$t_i^0 \leq t_i + dr_i \leq t_i^1, \quad \forall i \quad (12)$$

$$d_{ik}r_i - M(1 - y_{ik}) \leq dr_i \leq d_{ik}r_i + M(1 - y_{ik}), \quad \forall i, \forall k \quad (13)$$

$$Rmin \leq r_i \leq 1, \quad \forall i \quad (14)$$

Model C:

$$\sum_{i=1}^n r_i \rightarrow \max \quad (15)$$

$$x_{ij} + x_{ji} = 1, \quad \forall i < j, \quad (16)$$

$$u_i + 1 - M(1 - x_{ij}) \leq u_j, \quad \forall i \neq j, \quad (17)$$

$$\sum_{k=1}^K y_{ik} = 1, \quad \forall i \quad (18)$$

$$t_i + dr_i - M(3 - x_{ij} - y_{ik} - y_{jk}) \leq t_j, \quad \forall i \neq j, \quad \forall k \quad (19)$$

$$t_i^0 \leq t_i + dr_i \leq t_i^1, \quad \forall i \quad (20)$$

$$d_{ik}r_i - M(1 - y_{ik}) \leq dr_i \leq d_{ik}r_i + M(1 - y_{ik}), \quad \forall i, \forall k \quad (21)$$

$$Rmin \leq r_i \leq 1, \quad \forall i \quad (22)$$

5. Example

Let's have 5 vehicles and 2 charging stations. The vehicle requirements for charging and time windows for charging are listed in Table 1.

Table 1. Example – data

i	1	2	3	4	5
d_{i1}	2	1	9	8	4
d_{i2}	2	6	3	8	4
$t_i^0 - t_i^1$	8-12	8-14	12-20	13-20	15-23

Table 2 shows the results of the optimal solution of the model A. In this solution, vehicle 4 is not charged for capacity reasons, for other vehicles that are being charged, the start time of charging is indicated in line t_i , and the end of charging in the next line.

Table 2. Optimal solution: result of model A

i	1	2	3	4	5
k	1	1	2	-	1
t_i	8	10	12	-	15
$t_i + d_{ik}$	10	11	15	-	19

Table 3. Optimal solution: result of model B

i	1	2	3	4	5
k	1	1	2	1	2
t_i	8.875	8	12	13	15
r_i	0.875	0.875	0.875	0.875	0.875

Table 4. Optimal solution: result of model C

i	1	2	3	4	5
k	1	1	2	1	2
t_i	8	10	12	13	15
r_i	1	1	1	0.875	1

Optimal solution of model B involves charging all vehicles, but charging times have been reduced for all of them. The optimal value $Rmin = 0.875$. The values of variables r_i are not maximized in the model B, so we will use the model C to maximize them. In Table 3, all r_i

values are equal to 0.875. If we use this value as a lower limit for r_i in the model C, the values r_i for vehicles 1, 2, 3, 5 have increased to the value 1 (see Table 4).

6. Conclusions

The presented models represent a proposal for modeling the problem of scheduling electric vehicles during charging. These models can easily be supplemented with other charging conditions, e.g. vehicle priorities, vehicle handling times, etc.

Conflict of interest: none

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Barriers to the Use of Renewable Energy Sources

Teresa PIECUCH^{1*}, Katarzyna CHUDY-LASKOWSKA¹, Elżbieta SZCZYGIEL² and Łukasz NAWROT³

¹ Rzeszów University of Technology, Rzeszów, Poland; tpiecuch@prz.edu.pl; kacha877@prz.edu.pl

² University of the National Education Commission, Cracow, Poland; elzbieta.szczygiel@uken.krakow.pl

³ Centre of Sociological Research, Szczecin, Poland; l.nawrot25@gmail.com

* Corresponding author: tpiecuch@prz.edu.pl

Abstract: The article discusses the main barriers to the use of renewable energy sources among entrepreneurs. It presents the results of a survey of 717 Polish small and medium-sized enterprises operating in the tourism sector. The subject of the study was the determinants of investment in renewable energy sources (RES). The research was carried out in two groups; those using RES and those not using RES. The aim of the article was to identify the main barriers that cause the lack of use of RES and the lack of intention to use these sources in the future. The study used statistical tests, factor analysis and econometric modelling. The analysis was carried out at a significance level of $\alpha=0.05$). The research showed that the main barrier identified during the study was too high investment outlays and a long payback period.

Keywords: renewable energy sources (RES); small and medium-sized enterprises; barriers

JEL Classification: C5; O3; Q2

1. Introduction

Renewable energy sources (RES) have huge potential. They are based on the forces of nature, are not exhaustible and do not pollute the environment. They are derived from natural processes and resources, are sustainable and have minimal environmental impact. They are an excellent 'green' alternative to depleting and polluting fossil fuels. Their use brings a range of benefits to the economy and to those who use them. However, there are barriers to investing in RES (Sobocińska, 2022; Kudurs et al., 2020; Jayaprabha et al., 2024; Tomaszewski & Sekściński, 2020). The study was based on the available literature on the subject and on extensive own research among small and medium-sized enterprises operating in the Polish tourism sector. It focused on the conditions for investing in renewable energy sources, and the respondents included both entrepreneurs who use renewable energy sources and those who have not decided to use them.

Due to the broad understanding of the relationship between using of renewable energy sources by enterprises and the barriers in its implementation, it was decided to conduct a systematic literature review. In the first stage of the review, it was decided to select a bibliographic database that would allow a detailed analysis of scientific publications. The SCOPUS database was chosen for this purpose. In the second stage, the keywords considered

and the conjunctions linking the phrases were developed. This resulted in combinations presented on the Figure 1.

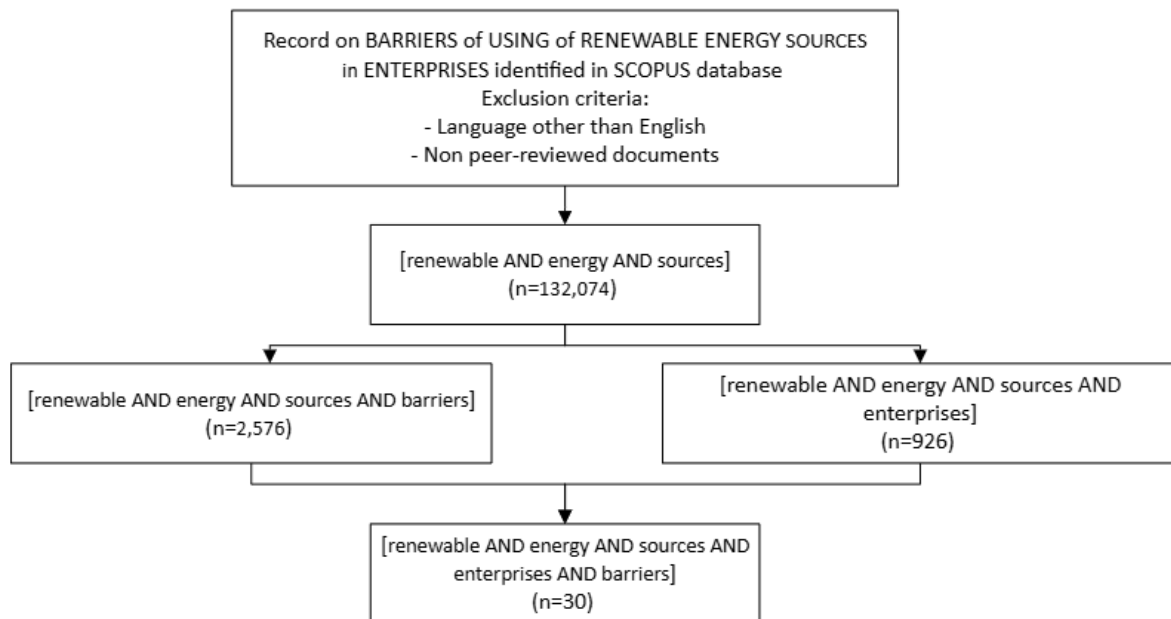


Figure 1. Selection of sources of literature review

Based on the identified literature, it was possible to identify the most commonly identified factors holding companies back from making the energy transition decision. Research by Kudurs et al. (2020) suggests that limiting the use of RES in companies is related to other investment priorities, long payback periods and constraints due to existing infrastructure. Long payback periods are also highlighted by other studies (Jayaprabha et al., 2024). These studies address the issue of storing energy generated during periods of sunshine (the study looked at solar energy) for use during periods without access to sunlight. This requires additional investment in renewable energy infrastructure. Despite EU subsidies and compliance with environmental requirements, the company's financial contribution is a factor that can be an obstacle to implementation at company level (Florkowski & Rakowska, 2022). Similar issues, albeit in the context of individual RES installations (at household level), are highlighted in the study by Karasmanaki et al. (2024). Investment costs are the main barrier to RES investment, and cost barriers slow down investment and reduce the rate of deployment. Qamar et al. come to similar conclusions, indicating that perceived price, perceived level of competition and energy cost intensity of businesses are barriers to RES adoption and diffusion (2022). Among the internal, company-specific factors, the main barriers to the implementation of RES were found to include: (1) poor environmental concerns on the part of company personnel, expressed in terms of fear of air pollution resulting from energy consumption; (2) low awareness and knowledge of renewable energy due to previous bad experiences, or (3) assessment of the total cost of renewable energy production due to the fact that producing green energy can involve additional costs or high initial outlay (Lyakurwa, 2023). Internal factors such as fierce market competition, limited company financial resources, risk aversion or the complexity of the technology were responsible for the lack of company investment in sustainable energy technologies. (Meijer

et al., 2019). Importantly, factors such as loss of time or institutional inertia of the firm were rated as less important barriers in this regard. Among the available publications, only one dealt with the tourism-related industry (Sardianou & Kostakis, 2019). This study analysed hotels in Crete. According to hoteliers, economic, institutional and human factors were the main barriers to investing in RES. These included budgetary barriers: (1) lack of financing or (2) high investment risk. These two were identified as the most important barriers to the adoption of RES in hotels. The second category of barriers were bureaucratic barriers related to the adoption of relevant investments. In addition, the study also identified physical limitations (50%), the level of education of staff (70%), or the lack of knowledge of know-how in the implementation of renewable energy sources (60%) (Sardianou & Kostakis, 2019). The administrative and bureaucratic barriers mentioned here, which lead to a lack of investment in and implementation of RES technologies in the operations of small and medium-sized enterprises, are also indicated by the Celic & Lenz study (2022). These studies indicate that an unclear system of bodies responsible for RES issues, lack of information, difficult application procedures for investments or overly complicated forms of their control are responsible for the shortcomings in the implementation of RES in enterprises. The barriers identified can also be grouped into the general category of lack of stable regulation, which is a result of the changing and evolving nature of RES regulation. These are mostly external, systemic and developmental barriers (Bednarek et al. 2023). The lack of a stable policy to promote renewable energy sources, including an energy market monopoly or the lack of a coherent sustainable development policy for air protection, and the lack of mechanisms to support the reduction of the energy intensity of the economy have been identified as barriers to the implementation of RES at the level of individual users (Wojciechowska-Solis & Soroka, 2018). Due to their systemic nature, they can also be considered as business factors. Similar barriers, i.e. the cost of investment, the lack of adequate subsidies and complex legal frameworks, the price of electricity, the low capacity of electricity grids, the length of the investment process, the need for additional investments (e.g. roof retrofitting), are identified by experts (My, 2024).

An important issue raised when analysing barriers to RES deployment is the impact of the deployment itself, which contributes to the competitiveness of companies (Cong & Uyen, 2020). Maintaining a company's intention to implement RES turns out to be a key factor at the level of internal factors. However, it is important that the energy and economic efficiency of the projects envisaged for implementation are satisfactory both for the companies and for the agencies intermediating their funding (Prokhorova et al., 2023; Sen & Ganguly, 2017). In the case of external factors, the role of a well-functioning RES system is emphasised, including access to RES operators. If there are none, or not enough, even the willingness of companies to implement RES will not translate into actual implementation for infrastructural reasons. In fact, the lack of responsiveness of the RES supply chain is identified as a key barrier to RES deployment in companies, as are bureaucracy and constraints in deployment planning (Mason-Jones et al., 2022).

It is therefore necessary to develop appropriate measures at the level of administrative and legislative solutions to encourage companies to implement RES in their activities.

Furthermore, companies should have access to information on available RES technologies and financial instruments, as well as the possibility to receive advice on the implementation of these technologies. (Kudurs et al., 2020). This issue is also highlighted by the Celic & Lenz study (2022), which calls for the creation of an optimal policy with an innovative financial instrument dedicated to companies wishing to invest in RES.

2. Methodology

The aim of the research was to find out what barriers make entrepreneurs in the Polish tourism industry reluctant to invest in renewable energy sources, and what factors could influence a positive decision to invest in renewable energy sources in the longer term. The analysis is based on data obtained from a diagnostic survey conducted using a questionnaire among companies operating in the tourism industry in Poland. A total of 1196 entrepreneurs participated in the survey, of which 140 entrepreneurs used RES (12% of the total group) and 1056 entrepreneurs did not use any such technology (88%). The group analysed in this study are entrepreneurs who do not use RES and do not plan to use these technologies in the next 3 years. The total size of this group was 717 entrepreneurs (representing 60% of the total group surveyed and 68% of the group not using RES in their business). The study used statistical tests, factor analysis and econometric modelling. The analysis was performed at a significance level of $\alpha=0.05$.

3. Results

The characteristics of the enterprises surveyed are shown in Table 1.

Table 1. Characteristics of the surveyed entrepreneurs who not using RES

	Specification	N	%
Type of business	Feeding	381	53
	Accommodation	336	47
Type of facility	Preparing and delivering food for external recipients (catering)	24	3
	Restaurants and other permanent catering establishments	357	50
	Tourist accommodation facilities and short-term accommodation	204	28
	Other accommodation	32	4
	Hotels and similar accommodation facilities	100	14
Ownership of premises	Yes		26
	No, we have our own premises		74
No. of employees	to 9	603	84
	from 10 to 49	108	15
	from 50 to 249	6	1
How long has the company been in the market	min, max	0.5; 73	
	mean	13	
	median	12	
	std.dev	8,5	

Most respondents operated a food business (53%), with half owning restaurants or other fixed food outlets. The vast majority (74%) did not own the premises in which they operated. As many as 84% of respondents were micro-enterprises, employing up to 9 people. The average duration of entrepreneurship is around 13 years. The shortest period for running an

enterprise was six months and the longest was 73 years. Most enterprises were located in Mazowieckie Province (15%) and Pomorskie Province (14%). The fewest, 2% each, were located in Podlaskie Province, Lubuskie Province, Opolskie Province and Świętokrzyskie Province (Figure 2.).

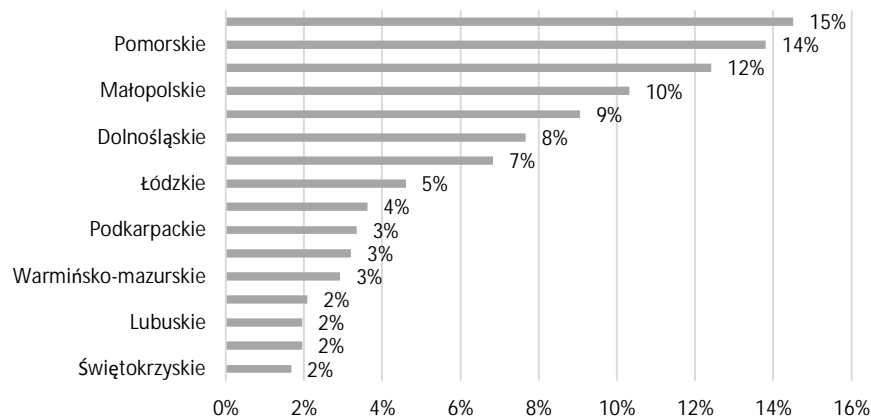


Figure 2. Province in which the surveyed enterprises operate, broken down by RES users and non-users

One of the aims of the research was to find out what the main barriers are that prevent tourism entrepreneurs from investing in renewable energy. What prevents them from planning such investments in the near future. The barriers were ranked on a scale from 1 – least impact to 10 – most impact. The ranking of the barriers is shown in Figure 3.

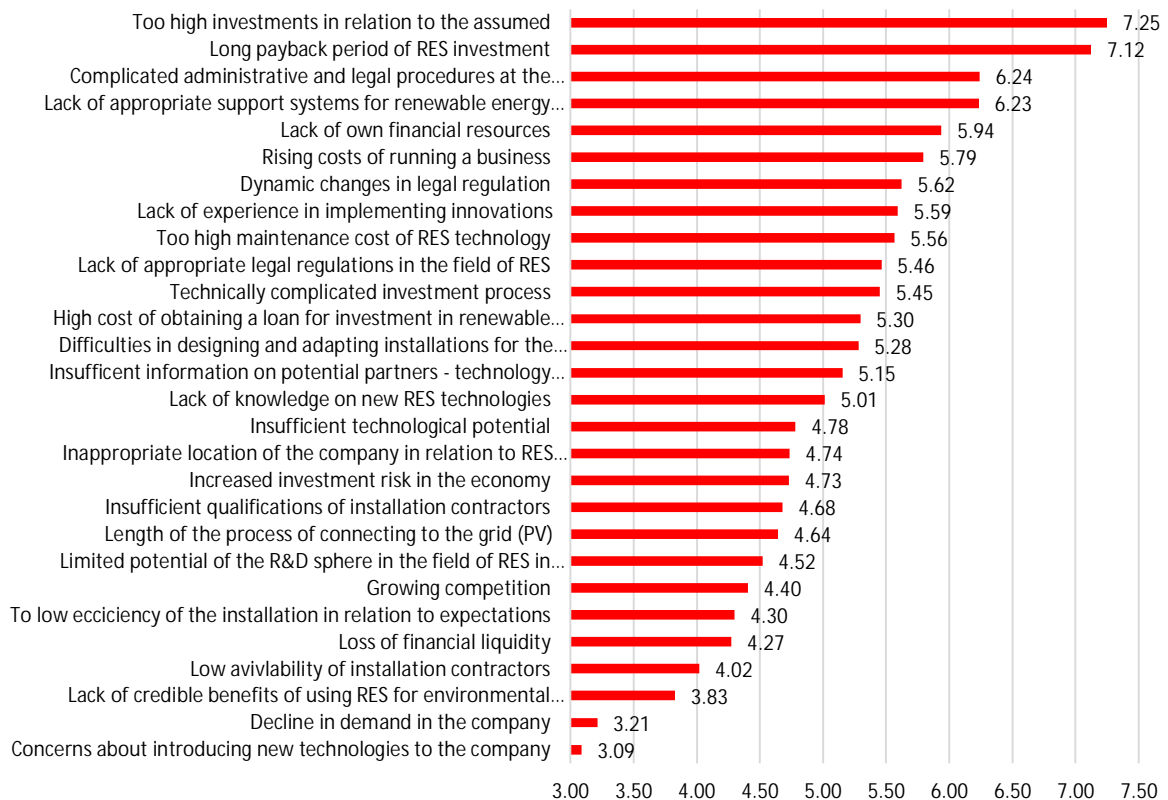


Figure 3. Ranking of importance of barriers to RES investment abandonment

Two barriers to investment in RES were rated above 7 points and thus had the greatest influence on entrepreneurs' reluctance to invest in RES. These were: investment costs that were too high in relation to the expected ones - the highest rated with an average of 7.25 points, and the long payback period of investments in RES - with an average of 7.12 points. The next two barriers with a score above 6 points are: complicated administrative and legal procedures at the authorisation stage - 6.24 points, and lack of adequate support systems for RES investments - 6.23 points. Only in fifth place was the lack of sufficient own funds to finance the investment (5.94 points), and in sixth place was the increasing cost of doing business (5.79 points). This suggests that it is not financial barriers that most deter entrepreneurs from investing in renewable energy, but rather the length of the payback period and the belief that investment costs will be higher than expected.

The research investigated whether there were differences in the perception of barriers among tourism entrepreneurs depending on the type of business they operated - whether it was catering or accommodation, whether they owned or rented, and whether the size of the business determined the occurrence of specific barriers to investment in RES. Non-parametric tests of significance, Mann-Whitney U test and Kruskal-Wallis ANOVA were used for the study. The results are presented in Tables 2, 3 and 4.

The analyses carried out show that the type of activity influenced the assessment of the following three barriers limiting RES investments: too high investments in relation to the assumed targets $p < \alpha$ ($p = 0.0404$), complicated administrative and legal procedures at the permit stage $p < \alpha$ ($p = 0.0202$) and technologically complicated investment process $p < \alpha$ ($p = 0.0478$) (Table 2).

Table 2. U Manna-Whitney test – type of activity vs. assessment of RES investment barriers

Barriers	p-value
Too high investments in relation to the assumed	0.0404*
Complicated administrative and legal procedures at the permitting stage	0.0202*
Technically complicated investment process	0.0478*

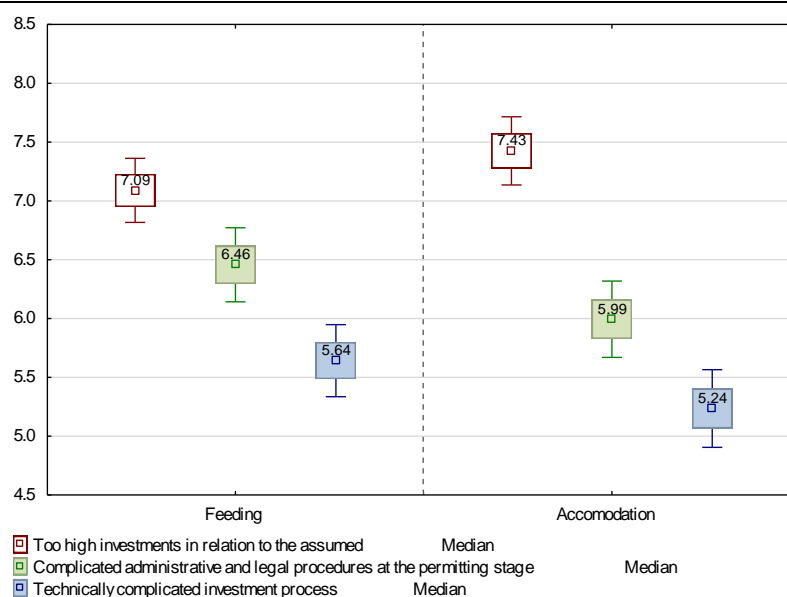


Figure 4. Assessment of barriers influencing the abandonment of investments in renewable energy sources in relation to the conducted business activity

Too high costs in relation to the RES to be installed are feared by those in the hotel sector (mean score 7.43), while complicated administrative and legal procedures at the licensing stage (6.46) and a technically complicated investment process (5.64) are more limiting for those in the catering sector (Figure 4).

For enterprise size, there were differences in the assessment of the following five barriers: loss of liquidity $p < \alpha$ ($p = 0.0357$), high cost of obtaining a loan to invest in RES $p < \alpha$ ($p = 0.0260$), insufficient information about potential partners $p < \alpha$ ($p = 0.0896$), long payback period for RES investments $p < \alpha$ ($p = 0.0264$) and lack of funds to invest in RES $p < \alpha$ ($p = 0.0083$) (Table 3).

Table 3. Kruskal-Wallis ANOVA – size of enterprise vs. assessment of RES investment barriers

Barriers	p-value
Loss of financial liquidity	0.0357*
High cost of obtaining a loan for investment in renewable energy sources	0.0260*
Insufficient information on potential partners - technology suppliers	0.0896*
Long payback period of RES investment	0.0264*
Lack of own financial resources	0.0083**

Loss of financial liquidity was most feared by entrepreneurs of the largest enterprises with between 50 and 249 employees – the average score for this barrier was 7.17 points. Large enterprises were also concerned about the high cost of borrowing for RES investments – average score 5.50 points – and the lack of financing sources – 6.33 points. Lack of or insufficient information on potential partners and technology suppliers, with an average score of 5.28, was a concern for entrepreneurs in micro-enterprises employing up to 9 persons, as was the long payback period for RES investments, with an average score of 7.24. (Figure 5).

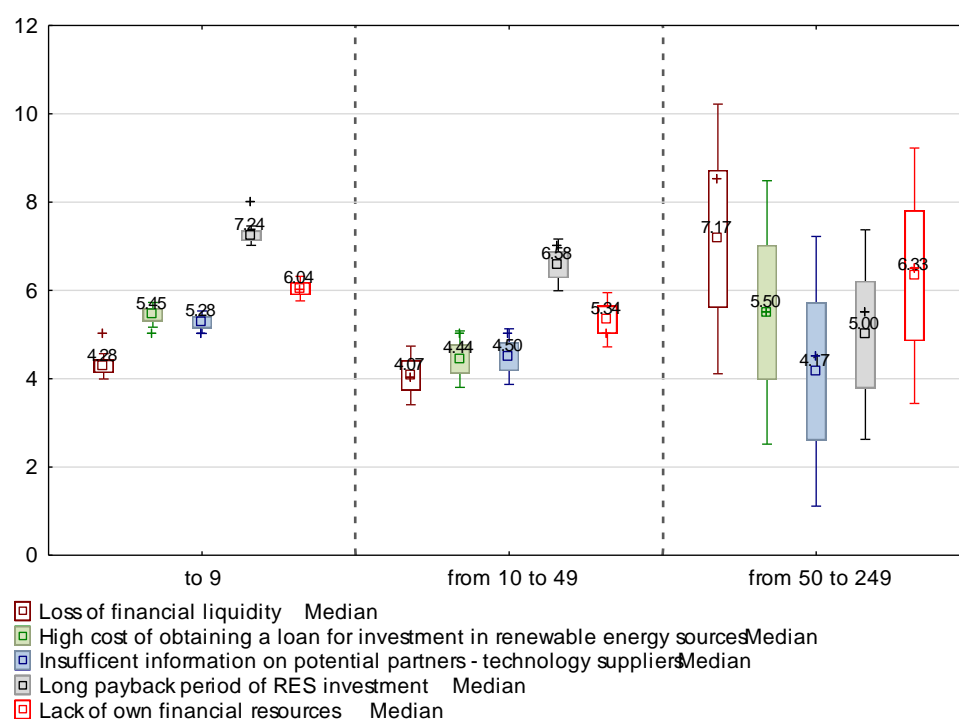


Figure 5. Average scores for each barrier in groups based on enterprise size

The last criterion used in the research was whether (or not) the respondents had their own premises where their business was carried out. Having own premises was related to the assessment of two barriers - inappropriate business location in relation to RES resources $p < \alpha$ ($p = 0.0098$) and lack of adequate support systems for RES $p < \alpha$ ($p = 0.0466$) (Table 4).

Table 4. Kruskal-Wallis ANOVA - ownership of premises vs. assessment of RES investment barriers

Barriers	p-value
Inappropriate location of the company in relation to RES resources	0.0098**
Lack of appropriate support systems for renewable energy sources	0.0466*

Inadequate business location in relation to RES was more feared by entrepreneurs who had their own premises in which to operate - the average score for this barrier was 5.31, while lack of adequate legislation in the field of RES was feared by entrepreneurs who did not have their own premises and operated in rented premises - the average score was 5.56 (Figure 6).

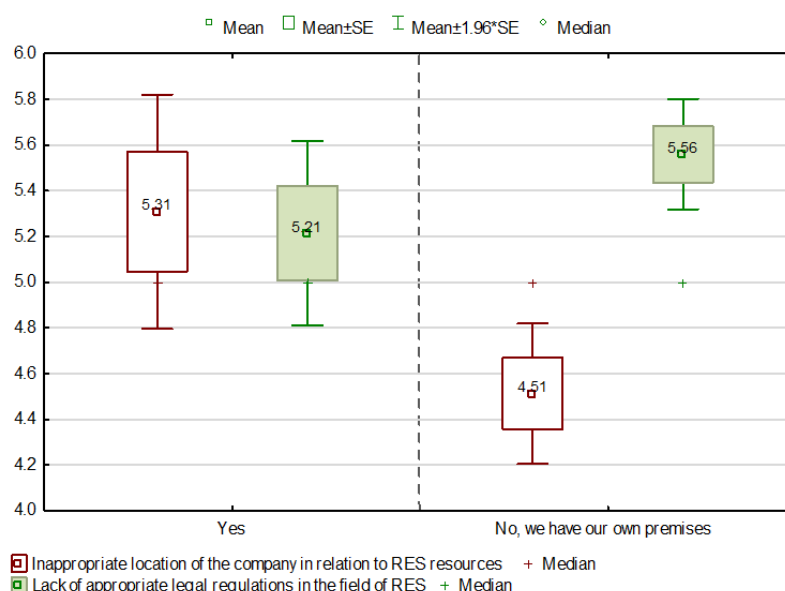


Figure 6. Average scores for each barrier in groups based on ownership of premises

The respondents were entrepreneurs who had not invested in RES and had no intention of doing so. They were therefore asked what factors would persuade them to make a decision to invest in RES. The highest scores were given by the entrepreneurs surveyed to tax incentives for the use of RES technologies – average score 7.31 points – and to shortening the payback period of investments – average score 7.21 points. Reducing the cost of RES technologies came in third, with an average score of 7.11, and improving the support systems for RES in Poland came in fourth, with an average score of 7.11. On average, entrepreneurs rated transparent administrative and legal procedures for RES with 6.97 points (Figure 7).

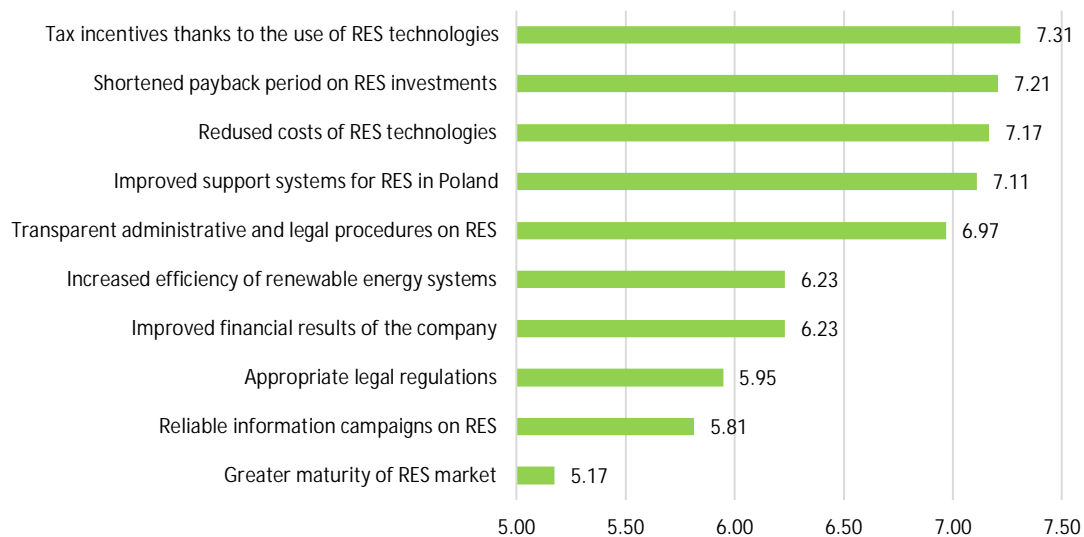


Figure 7. Ranking of factors that could influence a positive decision on RES investments

The research looked at whether the factors that could encourage investment in renewable energy were related to the size of the business, the type of business and whether they had their own premises where the business was carried out. The research shows that neither the size of the enterprise nor the type of enterprise is related to the assessment of factors that would lead entrepreneurs to decide to invest in RES. Only one factor – reduced payback period for RES investments – was related to whether the entrepreneur owned his own premises $p < \alpha$ ($p = 0.0356$). Those entrepreneurs who did not have their own premises rated the shorter payback period significantly higher – mean 7.32, median even 9 points (Figure 8).

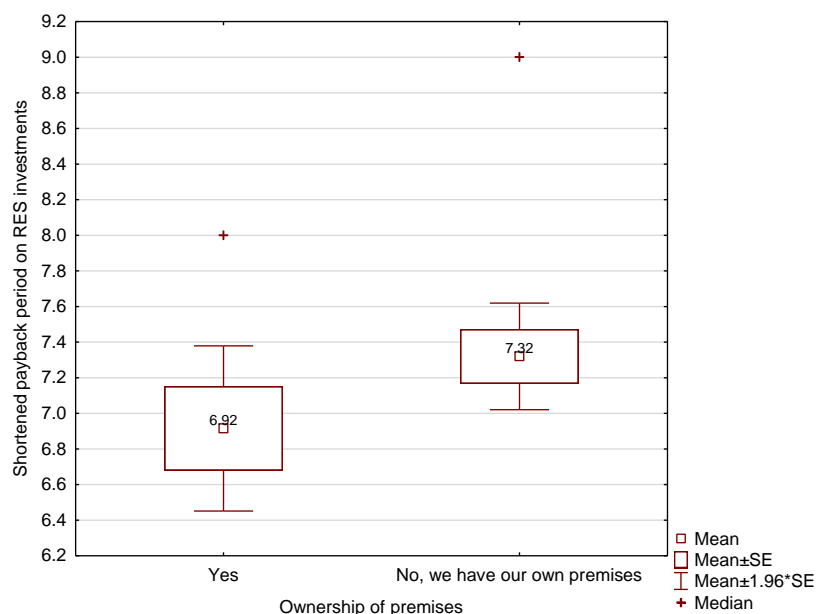


Figure 8. Average rating for reduced payback time for RES investments by whether entrepreneurs have their own business premises

If conditions were to change, some of the entrepreneurs said they would like to invest in renewable energy sources. They were therefore asked in which technology they would be most likely to invest. More than 50% said solar panels, 38% would invest in photovoltaics

and 17% in heat pumps. Biomass was the least popular, with only 1% of respondents saying they would be willing to invest in it.

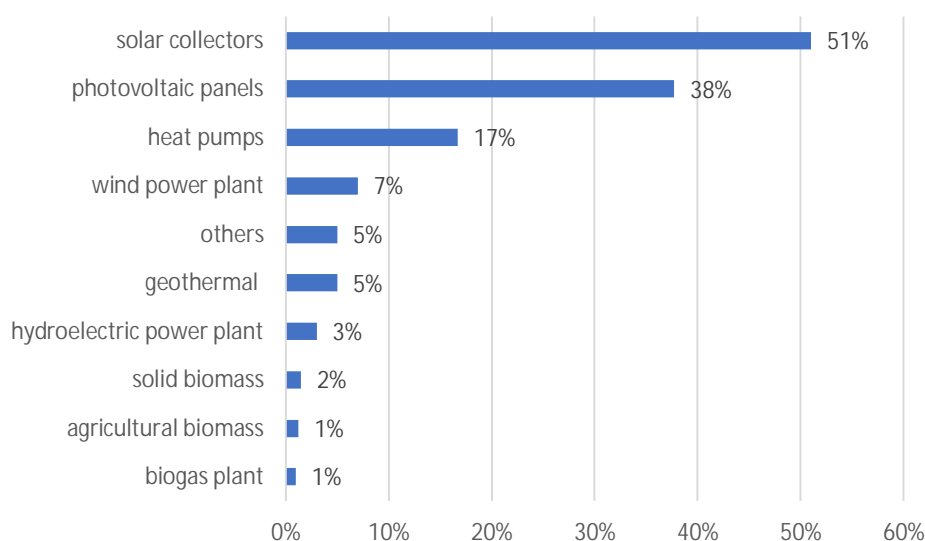


Figure 9. Technology that may be of interest to entrepreneurs if certain conditions are met

The entrepreneurs surveyed were also asked whether they were familiar with the Sustainable Development Goals (the UN's list of overarching development goals for 2015).

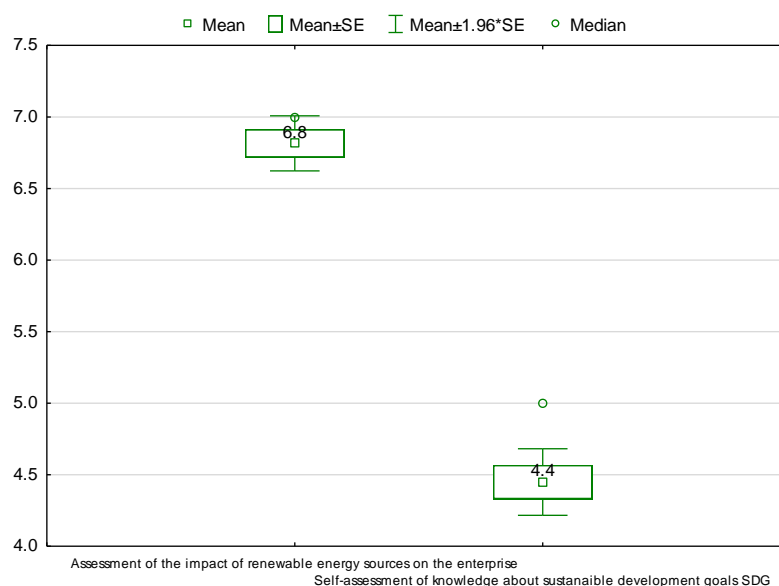


Figure 10. Self-assessment of knowledge of SDG sustainability targets, and assessment of the impact of renewable energy sources on the company

Only 35% of respondents said they were familiar with the Sustainable Development Goals, and they rated their knowledge of the subject at an average of only 4.4 on a scale of 1 to 10.

4. Discussion

The discussion of the results is limited due to the lack of studies directly related to the tourism sector. Nevertheless, it was decided to compare the main barriers with the available

literature discussed in the introduction. The main barrier diagnosed in this study related to the investment costs being too high in relation to the expected ones. This finding is similar to that of Karasmanaki et al. (2024) or Lyakurwa (2023). Similarly, the second main factor, the long payback period for RES investments, was confirmed in the studies by Kudurs et al. (2020) and Jayaprabha et al. (2024). The complicated administrative and legal procedures at the permitting stage identified in the presented studies have also been highlighted in previous studies (Celic & Lenz, 2022; Mason-Jones et al., 2022; Sardianou & Kostakis, 2019). Similarly, the lack of adequate support schemes for RES investments, which was identified as the fourth most important barrier, has also been mentioned previously in the literature (Celic & Lenz, 2022). The lack of sufficient equity to finance investments or the rising cost of doing business, although not identified as critical, was also highlighted in a study by Sardianou & Kostakis (2019). Lack of or insufficient information about potential partners and technology suppliers, which was identified as a barrier in microenterprises, was also mentioned in studies by Kudurs et al. (2020), Celic & Lenz (2022) or Sardianou & Kostakis (2019). Significantly, the barrier of inappropriate business location in relation to RES, feared by entrepreneurs with their own premises, was also mentioned in the study by Jayaprabha et al. (2024). On the other hand, the lack of appropriate regulation in the field of RES, which was feared by entrepreneurs who did not have their own premises, was indicated by Bednarek et al. (2023). This means that the results obtained in the present research are consistent with previous results conducted for different economies and different sectors, although they are largely consistent with the results conducted by Sardianou & Kostakis (2019) for the hotel sector.

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Conflict of interest: none

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The Essence and Importance of Cross-Border Cooperation in Water Management. The Example of Poland and the Czech Republic

Arkadiusz PIWOWAR^{1*} and Maciej DZIKUĆ²

¹ Wrocław University of Economics and Business, Wrocław, Poland; arkadiusz.piwowar@ue.wroc.pl

² University of Zielona Góra, Zielona Góra, Poland; ma.dzikuc@wez.uz.zgora.pl

* Corresponding author: arkadiusz.piwowar@ue.wroc.pl

Abstract: This perspective article outlines new ways of thinking and innovative approaches to water planning and management to address complex issues. Due to the geographical location of Poland and the Czech Republic, cross-border cooperation is a crucial element of water management. This is becoming more and more important due to the increasingly frequent extreme weather phenomena in this part of Europe, which have negative social and economic consequences. The aim of this paper is to characterize the scope and forms of cross-border cooperation, including the prospects for further development in this area. The authors' intention was to present the issues in a broader context, drawing attention to the significant importance of cross-border cooperation both in the field of water security (flood and drought protection) and selected categories of the economic use of rivers (agriculture, energy, tourism, etc.). The conclusion is that solving the problems of groundwater and surface water in the border area requires new ways of thinking, developing and implementing water planning and management practices. This could include AI applications for predictive modeling, data analysis, and real-time monitoring.

Keywords: water management; cross-border cooperation; border regions

JEL Classification: Q25; Q56; R11

1. Introduction

The essence of water management is to maintain ecological security and ensure the supply of disposable water resources that can be used for economic and social purposes while maintaining economic efficiency. This requires expansion of the prevailing water resources management paradigm beyond narrow economic criteria to include socially valued ecosystem functions and services (Poff et al., 2016). In the researched topics, analyses of climate change and its impact on the supply and use of water resources are very important. Most natural catastrophes in the globe are caused by water-related risks like floods and droughts, and it is predicted that climate change will make these water crises more frequent and more severe (Stańczuk-Gałwiazek et al., 2018). Droughts and floods are becoming more frequent and severe due to socioeconomic advancements and climate change (Wang et al., 2022). Due to the fundamental importance of water in the field of private and public safety, this topic is analyzed in various fields and scientific disciplines, including social sciences

(Piwowar et al., 2021; Markowska et al., 2020). This is due to the fact that effective implementation of water policy is of fundamental importance in ensuring sustainable socio-economic development (Janczewska et al., 2023). However, rapid and significant changes in environmental and social systems complicate attempts to assure water-secure conditions (Varady et al., 2020). The literature on the subject contains a lot of methodological and analytical works on the phenomenon of floods and droughts. Nevertheless, despite advanced measurement techniques (such as numerical weather prediction), predicting hydrological events and effects remains a difficult research task. Currently, in the area of water management, the role of flood risk management methods and techniques is emphasized, including the role of animate and inanimate elements of water management supporting sustainable flood risk management and, more broadly, adaptation to climate change (Thaler et al., 2023). Water resources management encounters a lot of difficulties and obstacles. In this regard, various uses of water are indicated for drinking and living purposes, navigation, hydropower generation, flood protection, tourism and recreation. Moreover, these are uses that are often contradictory, and the satisfaction of one makes it difficult to implement the other (Kliot et al., 2001).

This paper is part of the considerations on cross-border perspectives of development of science and policy in the field of water management (Ingold et al., 2016). Thus, it includes difficulties related to international policy and realization of individual countries' own interests in the field of water management. This also complicates the design and implementation of adaptation responses. The basic subject scope of this work concerns the issue of cross-border connections in the field of water management between Poland and the Czech Republic, mainly the Odra river basin (Fig. 1). The Oder River is one of the major rivers shared by Poland and the Czech Republic. It plays a crucial role in the water management strategies of both countries.

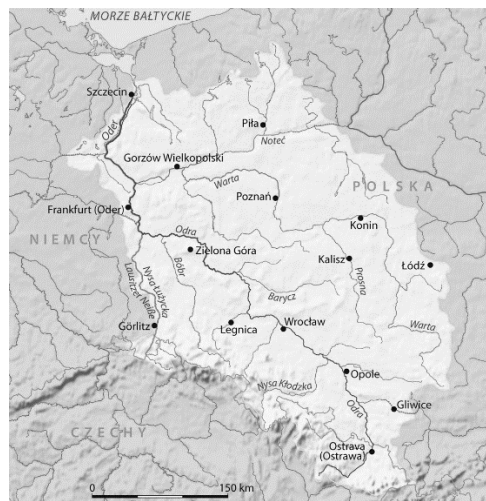


Figure 1. The Oder/Odra river basin

The axis of the common area is primarily the Odra River, and the international Odra River Basin covers the areas of: 7,217 km² (Czech Republic), 5,587 km² (Germany) and 106,057 km² (Poland). The Czech part of the Odra River Basin is the upper part of the international Odra

River Basin (the Baltic Sea basin), where the main stream of the entire basin - the Odra River - also originates. The length of the Odra in the territory of the Czech Republic is 132.3 km, the remaining length in the territory of the Republic of Poland, up to the mouth on the Baltic Sea, is 734.3 km (https://www.pod.cz/planovani/pl/oblast_povodi_odry.html).

The ongoing climate change is a challenge for all countries in the world, including the countries of Central and Eastern Europe. Almost every year, climate change manifests itself in this area with extreme weather phenomena, including heat waves, droughts and heavy rainfall (Řehoř et al., 2024; Labudová et al., 2024). In the studied area (Poland, Czech Republic), dramatic floods often occur, especially in mountainous areas (the last flood in September 2024). Climate change and weather extremes are an important topic, among others, in the field of probabilistic modelling (Piwowar & Kuźmiński, 2023), but also a broad research topic in the field of institutional aspects of water management, including monitoring and cooperation issues (Sivakumar, 2011; McCracken, 2022; Hasan et al., 2023).

The aim of this paper is to characterize the scope and forms of cross-border cooperation, including the prospects for further development in this area. The research question of this paper was: What innovative approaches and technologies can be applied to improve cross-border water management between Poland and the Czech Republic? The authors' intention was to present the issues in a broader context, drawing attention to the significant importance of cross-border cooperation both in the field of water security (flood and drought protection) and selected categories of the economic use of rivers (agriculture, energy, tourism, etc.). Most communities are at a risk of water scarcity in central Bohemia and Southern Moravia (Kročová & Kavan, 2019). Droughts in Poland are also becoming more intense and cover large areas (<https://www.umcs.pl/pl/aktualnosci,4622,susze-atmosferyczne-iglebowe>). It should be noted that Poland has modest water resources, one of the lowest in Europe (Majewski, 2015). There is a noticeable gap in the research on the involvement of important stakeholders in cross-border cooperation in this area in the studied region.

The paper is structured into 4 sections: Section 1 is the introduction; Section 2 presents the aim, methods and data; Section 3 presents cooperation in the Czech Republic and Poland border area on water management sustainability; Section 4 discusses the results and draws a conclusion.

2. Methodology

The work uses a wide range of Polish and Czech source data, official documents on the scope and form of cross-border cooperation in the field of water management. The basic time frame of the analyses covered the years 2015-2023. The beginning of this period is associated with the signing of a relevant cooperation agreement between the Republic of Poland and the Czech Republic. The research methods used in the article are: analysis of literature and documents, deductive method, cause-effect analysis and observation. The methodology primarily focused on the qualitative technique of source document analysis, which entails examining the phenomena described, their content, and their interpretation. The scientific difficulty was resolved by reviewing the accepted regulations and *de lege ferenda* postulates developed on this foundation. The methodology used was required to analyze and describe

the observed reality. The basis for writing this paper were documents of the Ministry of Infrastructure posted on websites. Understanding these frameworks can help identify areas for harmonization and collaboration and potential legal and regulatory challenges. Such a selection of research material was aimed at analyzing the current state and possibilities, methods, ways of developing relations in the researched subject area. The literature on the subject was also used in the scope of the importance of water management, including cross-border cooperation. The proposed considerations are a stage of broader research related to water management. The publication addresses a number of issues that constitute an important contribution to expanding interesting thematic threads concerning not only the protection, but also the management of water, in terms of tourism and recreation.

3. Cooperation in the Border Area on Water Management Sustainability – Current and Prospect

Introduction of sustainability criteria to water resources planning and management was realized for the first time in 1998 by ASCE's (American Society of Civil Engineers) Task Committee on Sustainability Criteria (Task Committee on Sustainability Criteria, 1998; Harmancioglu et al., 2013). Generally, three basic criteria, namely social, economic and environmental, are important to infer on sustainability in water resources systems. Water management, politics, and governance analysis should include context, case, and country-specificities (or countries on cross-border) (Ingold et al., 2016). Cross-border cooperation can enhance resilience to climate change and mitigate its adverse effects on water availability and quality (Cots et al., 2009; Bălan, 2020).

The basis for cross-border sustainability are strong institutional mechanisms, strategic and operational capabilities enabling joint action to improve water management in line with the idea of social justice, taking into account environmental protection policy and the implementation of economic goals. Cooperation can take various forms and can be implemented on many levels.

Poland and the Czech Republic actively cooperate on cross-border waters, which takes place within the framework of a bilateral commission and the International Commission for the Protection of the Odra River against Pollution (ICOPO) (Szumiejko & Skąpski, 2021). A close cross-border cooperation began with the signing of the first agreement between the Government of the People's Republic of Poland and the Government of the Czechoslovak Republic on water management on border waters on 21 March 1958. The Agreement between the Republic of Poland and the Czech Republic on cooperation on border waters in the field of water management was signed in Prague (Czech Republic) on 20 April 2015. The main objective of the cooperation is to ensure protection, mutually coordinated and rational use of border waters and improvement of their quality, while maintaining and restoring ecosystems dependent on waters. Moreover, the conscious use of border waters, their protection against pollution, as well as coordination of efforts to mitigate the negative effects of floods and droughts are urgent and important tasks that can only be implemented through close cooperation between both countries. The cooperation within this commission is divided into

five areas (Table 1) and is implemented throughout the year within the Polish-Czech working groups, during joint work, consultations and meetings of experts.

Table 1. Scope of cooperation of working groups within the Polish-Czech Commission for Boundary Waters

S	Workgroup name	Description of tasks
R	Group for cooperation in the field of regulation of border watercourses, water supply and land improvement of border areas	Primarily supervision of the maintenance of border stream beds, water reservoirs and other facilities on border waters in the territory of their countries and their use so that they do not cause threats or damage to the other Party. Providing opinions on planned projects that may affect border waters. Providing opinions on projects in the field of land improvement in border areas. Cooperation with other Working Groups appointed by the Commission. On the Polish side, the tasks are carried out by the Regional Water Management Board in Gliwice, including the Catchment Board in Gliwice. On the Czech side, the Czech Water Management Company, i.e. Povodí Odry Ostrava, is responsible for cooperation.
P	Group for cooperation in the field of water management planning in border waters	Providing opinions on tasks mainly in the field of flood protection carried out or planned to be carried out on border waters. Cooperation with other Working Groups appointed by the Commission, including providing opinions on investments that may affect border waters.
OPZ	Group for cooperation in the area of protection of border waters against pollution	Monitoring of border waters through systematic studies of border waters, assessment of the quality of border waters based on unified analysis results, assessment of the status of border water bodies based on unified analysis results. The OPZ Group cooperates to prevent and eliminate the causes and effects of cross-border water pollution; takes action to reduce the pollution of border waters in order to achieve good water status. This Group issues opinions on documentation concerning undertakings affecting border waters or damage caused by cross-border extraordinary water pollution, cooperating with other Groups within the Commission. On the Polish side, the tasks are carried out by the Voivodship Inspectorate for Environmental Protection in Katowice and the Chief Inspectorate for Environmental Protection in Warsaw, and on the Czech side by the Ministry of the Environment of the Czech Republic.
WFD	Cooperation Group on the implementation of the Water Framework Directive 2000/60/EC in transboundary waters	Cooperation in the field of sustainable and rational use of shared transboundary water catchments, achieving good status of surface and groundwater and protected areas and preventing further deterioration of water status, protection and improvement of aquatic ecosystems, ensuring coordination and mutual information on the implementation of tasks undertaken to implement the EU Water Framework Directive in shared Polish-Czech transboundary water catchments. The Group cooperates in the process of developing and coordinating water management plans and their updates. The WFD Group cooperates with other Commission groups on tasks related to the Group's competences. On the Polish side, the Group's tasks are carried out by: the State Water Management Polish Waters Regional Water Management Board in Wrocław, the State Water Management Polish Waters Regional Water Management Board in Gliwice, the Chief Inspectorate for Environmental Protection Regional Environmental Monitoring Department in Wrocław and the Institute of Meteorology and Water Management - State Research Institute in Wrocław. On the Czech side, the Ministry of the Environment of the Czech Republic.

HyP	Group for cooperation in the field of hydrology, hydrogeology and flood protection	Coordination of tasks in the field of hydrology, hydrogeology and flood protection on border waters between the Republic of Poland and the Czech Republic. Coordination of cooperation between territorial branches of hydrometeorological services of both Parties. Proposals of solutions aimed at improving cooperation resulting from the needs of the national economy on border waters. Coordination of cooperation in the use of the latest measurement and observation techniques in flood protection. Carrying out tasks in the field of unification of hydrological characteristics on border rivers; conducts observations and measurements of groundwater. The HyP Group is responsible for exchanging the results of hydrological and meteorological measurements and observations, providing information and documentation in the field of hydrology and meteorology, exchanging hydrological forecasts for flood protection purposes, and also cooperates with other working groups operating within the Commission. On the Polish side, the tasks are coordinated by the Institute of Meteorology and Water Management – State Research Institute in Wrocław, while the Polish Geological Institute – State Research Institute, KWB Turów and the Regional Water Management Board in Gliwice are also involved in the work of the HyP Group. On the Czech side, the tasks are coordinated by the Czech Hydrometeorological Institute ("ČHMÚ").
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The scope of cooperation presented above includes the most important aspects, related to water pollution and flood risk. The form of cooperation is also important, which is largely implemented on an ongoing basis.

From the point of view of the hydrological protection carried out in the Odra catchment area, the tasks carried out by the Working Group for Hydrology, Hydrogeology and Flood Protection (HyP Group) are important. Within this team, working meetings and meetings of group leaders are held periodically. During the meetings, long-term plans and tasks (for the following years) are developed. Standard cooperation includes the mutual transfer of monthly and annual summaries of measurement results and observations of precipitation and flows; exchange of daily information on precipitation, water levels, flows and reservoir data for the needs of the flood service and hydrological forecasts, as well as daily meteorological protection. Activities during periods of high water and flood hazard are also essential. Additional information on precipitation, water levels and reservoir data and issued warnings are then exchanged (Szumiejko & Skąpski, 2021). In the years 2016-2023, 7 meetings of the Polish-Czech Commission for Transboundary Waters were held. The 1st meeting of the Commission was held on 21-23 September 2016 in Duszniki-Zdrój. The last meeting of the Polish-Czech Commission for Transboundary Waters in the period under review (7th in a row) was held on 6-8 November 2023 in Liberec, Czech Republic.

The possibilities of developing cooperation, including improving management and communication aspects are crucial within the framework of the undertaken topic and the aim of the work. The scientific basis of work within the Polish-Czech working groups are hydrology and water engineering, closely related sciences. Nevertheless, an important element of development in the studied subject matter are the skills of coexisting with the environment, including the transfer of information, which requires a quick assessment of the impact of natural phenomena on the socio-economic environment and an appropriate method of

communication. Although significant technical progress was made in the period under study (measurement techniques, transfer of information between the parties to the agreement, etc.), only a small degree of use is made of forms of informing and educating the public in the border areas that are adequate to the current conditions. Taking into account the increasingly frequent and violent weather phenomena, it is postulated to expand the information and educational aspects, including organizing meetings and education in schools, direct meetings with residents of border areas, professional consulting for residents and economic entities, cooperation with the media, use of the Internet. Education should include, among others: preliminary flood risk assessment, flood hazard maps, flood risk maps for a particular area.

The second aspect that can be implemented is a broader perspective on drought. The problem of water deficit has become a significant social and economic issue in Poland and the Czech Republic. The issues of water shortages and drought, including the causes, scope and consequences of drought, as well as plans and actions taken to prevent this phenomenon and minimize its effects, can be the subject of work by a separate, interdisciplinary team (working group). The reason is the current state and forecasts in this area, including the negative impact not only on border areas. Drought is a problem for agriculture, as well as many branches of industry: food, textile, chemical, paper, etc. Water shortage reduces the size and quality of crops in agriculture. Droughts are increasingly intensified during the period of active growth and development of plants. Models explain that a high percentage of yield variability of winter and spring cereals in the Czech Republic results from drought (over 45% of yield variability) (Potop et al., 2010). Wheat is the predominant cereal species cultivated in Poland. High wheat yield losses due to drought were over the 1992–2019 period (Oleksiak et al., 2022). Drought affects the decrease in electricity production in hydroelectric power plants. The development of the theoretical hydropower potential of the study catchments and the course of the meteorological drought were found to be statistically significantly correlated in the research study (Młyński et al., 2024). Huge amounts of water are also necessary to cool condensers in thermal power plants, including coal-fired power plants, which still dominate in Poland. Therefore, these power plants are often built near rivers. Additionally, open cooling systems are still used, which significantly interfere with ecosystems, as they can require even over 100 times more water than closed-loop systems. Counteracting the effects of drought is also a problem of forest management. Forests can influence the course of climate change by regulating water management, air quality, carbon dioxide sequestration, and even limiting climate extremes (Vacek et al., 2023). The topics of the work of the new team may include, among others, increasing retention capacities and counteracting drought in forest ecosystems in border areas. As mentioned earlier, this requires the establishment of an interdisciplinary team of experts.

On the other hand, broad cross-border cooperation (including public and private entities) may also to a greater extent concern the possibilities of economic and natural use of border waters without harming aquatic ecosystems. The recreational and tourist function of water resources is not the subject of broader analyses in this region (Polish-Czech border), but it may constitute an improvement in the competitiveness of border regions. There is great potential for the creation of reservoirs that could perform flood retention and tourist functions. The beauty and high natural values, biological and landscape diversity, combined with strategic

management of natural resources – surface and underground waters, may be the basis for creating programs for the development of water tourism in the border area. This is very important, because border areas are largely characterized by peripheral social and economic development (Pászto et al., 2019).

4. Summary and Challenges

As climate change deepens, the issue of water management may play an increasingly important role in creating and developing partnership-based cross-border relations between neighbouring countries. The basis for solving bi- and multinational water problems is the ability to respond and adapt to changing social, political and environmental conditions of the border region.

Based on the cooperation to date, including observed reactions and actions in the face of threats, further action is necessary to develop specific adaptation plans and respond to specific regional challenges (e.g. water pollution, so-called flash floods). While hydrometeorological and other physical data are easy to obtain and provide, the same is not true for socio-economic data. Further improvement actions are also necessary, especially in the area of information and education. This could be done by providing the groundwork for preparing guidance or even developing a decision support tool for key stakeholders. Big Data analytics and artificial intelligence (AI) would also be used. AI can undoubtedly play a significant role in supporting cross-border water management initiatives. AI can process vast amounts of data from various sources, such as weather patterns, river flow measurements, and water quality indicators, to more effectively predict and manage water-related issues. Using historical data, AI can create models to forecast extreme weather events like floods and droughts, allowing for better preparedness and response strategies.

Due to the fact that cross-border cooperation is a complex set of goals and conditions, it requires a special approach to management. New challenges in the field of water resources management entail the need to modify the existing forms of cooperation and the methods, tools and techniques used (including AI). Authors suggest that there is a need for conceptual work that is integrative and processual in nature. This means looking at water management not just as isolated tasks but as an ongoing, dynamic process that requires continuous adaptation and collaboration. It is necessary to take a broader look at the researched topics, including determining common possibilities of reducing negative phenomena (e.g. in the field of forestry development).

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Conflict of interest: none

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Application of Simultaneous Equations in Econometric Modeling

Alena POZDÍLKOVÁ^{1*}, Marie NEDVĚDOVÁ¹ and Martina HEDVIČÁKOVÁ²

¹ University of Pardubice, Pardubice, Czech Republic; alena.pozdilкова@upce.cz; marie.nedvedova@upce.cz

² University of Hradec Králové, Hradec Králové, Czech Republic; martina.hedvicakova@uhk.cz

* Corresponding author: alena.pozdilкова@upce.cz

Abstract: This paper focuses on analyzing simultaneous equations and their application in econometric modeling. We use various parameter estimation methods, including the classical ordinary least squares (OLS), generalized least squares (GLS), two-stage least squares (2SLS), three-stage least squares (3SLS), and maximum likelihood estimation (MLE). As a case study, we use Klein's macroeconomic model, which describes the relationships among key macroeconomic variables such as GDP, consumption, investment, and wages. The model is estimated using historical economic data, and the results are compared across methods. The results show that the 2SLS and 3SLS methods provide more consistent estimates than OLS. In contrast, the MLE method offers the highest efficiency when dealing with the probabilistic structure of the data. Finally, we discuss the advantages and limitations of these methods and their suitability for economic analysis.

Keywords: simultaneous equations; econometrics; least squares; Klein model; maximum likelihood method

JEL Classification: B23; D81; C69

1. Introduction

Nowadays, analyzing the relationships between different economic variables is crucial for understanding the complex interactions that affect economic systems (Greene, 2003; Wooldridge, 2011). As economies become more interconnected and dynamic, the need for sophisticated models that can capture these interdependencies has become even more pronounced. Simultaneous equations allow modeling and analysis of these relationships within dynamic economic systems and are an essential tool in econometrics. These models are particularly useful when dealing with interrelated variables, where each variable can serve as both an explanatory and an explained variable, reflecting the complexity of economic phenomena (Johnston & DiNardo, 1997).

In the context of macroeconomics, simultaneous equation models are indispensable in understanding key economic indicators such as national output, inflation, and unemployment, and their mutual influence. For example, in the case of supply and demand models, the price of goods can simultaneously be determined by both consumer preferences and producer costs, creating a circular relationship. In a broader macroeconomic setting, the

relationships between consumption, investment, wages, and GDP are often interconnected in such a way that changes in one variable affect others in a feedback loop. This interdependent structure makes it difficult to isolate the effect of any single variable without addressing the simultaneous nature of these relationships.

Simultaneous equation models are a system of interrelated equations where an endogenous variable explained in one equation may appear as an explanatory variable in another equation. This interdependent relationship between the variables precludes the use of classical regression methods because they assume the independence of the explanatory variables from the error component (Judge et al., 1985; Baltagi, 2008). Classical methods, such as ordinary least squares (OLS), cannot be directly applied to such models without leading to biased and inconsistent estimates. In contrast, simultaneous equation models provide a framework for capturing the interconnections among variables, allowing for a more accurate depiction of real-world economic systems.

To address the challenges of simultaneous equations, several advanced methods have been developed, including generalized least squares (GLS), two-stage least squares (2SLS), three-stage least squares (3SLS), and maximum likelihood estimation (MLE) (Bollen et al., 2007; Drukker et al., 2023; Ekmen & Karatepe, 2024). These methods aim to solve the issues of endogeneity and correlated errors that arise from interdependencies among variables. The generalized least squares method focuses on removing heteroskedasticity or autocorrelation of residuals that may distort the quality of estimates (Judge et al., 1985). The two-stage least squares method uses instrumental variables to replace endogenous variables, ensuring that the estimates are consistent (Johnston & DiNardo, 1997). The three-stage least squares method extends this approach to systems with multiple simultaneous equations, jointly modeling the covariance of error components, further improving the efficiency of the estimates (Greene, 2003).

The application of simultaneous equation models extends across a wide range of economic analyses, from microeconomic models of individual markets to complex macroeconomic frameworks. These models are integral to understanding the behavior of key economic variables and their interrelations. A notable example is the Klein model, which explores the relationships between gross national product (GNP), consumption, investment, and other important macroeconomic indicators (Bjerkholt, 2014; Visco, 2014). These models are critical for policymakers and researchers because they provide more accurate parameter estimates and a clearer understanding of the dynamics of economic systems, facilitating better economic predictions and decision-making (Baltagi, 2008).

Moreover, scientific research in the area of simultaneous equations continues to evolve, incorporating advanced technologies and methods. New approaches, such as Bayesian techniques (Bolstad, 2004) and the generalized method of moments (Hansen, 1982), offer greater flexibility in addressing nonlinear models or models with more complex data structures. These developments not only improve the efficiency and accuracy of econometric models but also expand their applicability to new, more intricate economic issues, such as those involving large datasets or emerging economic phenomena.

Klein's macroeconomic model and the IS-LM model are examples of economic models that use simultaneous equations to analyze interactions between key macroeconomic variables such as gross domestic product (GDP), investment, consumption, interest rates, and inflation. These models show how changes in one variable can affect others within the interdependent relationships between households, firms, government institutions, and central banks. For instance, in the IS-LM model, simultaneous equations illustrate how changes in interest rates affect investment, which in turn influences aggregate demand and output (Vergés, 2024). Klein's model, on the other hand, focuses on the relationships between gross national product, consumption, and investment, showing how macroeconomic shocks or changes in economic policy can impact the economy in both the short and long term. These models allow analysts, central banks, and governments to better understand complex economic dynamics and evaluate the effects of various policy tools, such as changes in interest rates or fiscal stimulus, on overall economic activity. In practice, the methodology of simultaneous equations provides valuable tools for modeling and simulating scenarios that help predict the potential consequences of economic decisions and optimize policy strategies to achieve macroeconomic goals such as stable growth, low unemployment, or controlling inflation.

The study of simultaneous equations remains at the forefront of econometric research, offering essential tools for analyzing the complex interactions that shape modern economies. The continued development and refinement of these methods are vital for advancing our understanding of economic systems and enhancing the ability to make informed, data-driven economic decisions.

2. Methodology

In this section, we focus on implementing four main methods for solving simultaneous equations: the generalized least squares method, the two-stage least squares method, the three-stage least squares method, and the maximum likelihood method. These methods will be described in more detail below.

2.1. Generalized Least Squares Method

The classical Ordinary Least Squares (OLS) method estimates the parameters of a regression model by minimizing the sum of the squares of the residuals (Hušek, 1999). This method assumes that the errors have zero mean and constant variance and are independent of each other (Baltagi, 2008). Mathematically, the parameter estimation is expressed by the relation:

$$y\hat{\beta} = (X'X)^{-1}X'y \quad (1)$$

where X is a matrix of independent variables, y is a vector of dependent variables, and $\hat{\beta}$ is a vector of estimated parameters.

The Generalized Least Squares (GLS) method allows us to overcome the limitations of the classical Ordinary Least Squares (OLS) method, especially in the presence of heteroskedasticity or autocorrelation of residuals. The basic principle is to transform the

model using a matrix Σ that represents the variance-covariance structure of the errors (Menke, 2015). This matrix can, for example, be estimated using robust methods or based on theoretical assumptions (Greene, 2003). Parameter estimation is then performed according to the equation:

$$\hat{\beta}_{GLS} = (X^T \Sigma^{-1} X)^{-1} X^T \Sigma^{-1} y \quad (2)$$

where X is the matrix of explanatory variables, y is the vector of the dependent variable, and Σ represents the covariance matrix of residuals. The transformation of the model removes dependence and heteroskedasticity, which ensures consistent and efficient estimation.

2.2. Two-Stage Least Squares Method

The Two-Stage Least Squares (2SLS) method is designed for cases where some explanatory variables are endogenous (Wooldridge, 2011; Greene, 2003). The process is carried out in two steps:

- Each endogenous variable is regressed on all available exogenous and instrumental variables (Johnston & DiNardo, 1997). This yields the predicted values of the endogenous variables, which are adjusted for the effect of correlations with the error term in the original regression model. Mathematically, this process is represented by the relation:

$$\hat{X} = Z(Z^T Z)^{-1} Z^T X \quad (3)$$

The predicted values are denoted as \hat{X} . Z is a matrix containing all exogenous and instrumental variables (Mogstad et al., 2021). This step allows the endogenous variables to be purged of the influence of the error component, ensuring that the resulting parameter estimates are unbiased and consistent (Judge et al., 1985).

- The original model is estimated using OLS, where the endogenous variables are replaced by their predicted values. Mathematically, the parameter estimation is given by:

$$\hat{\beta}_{2SLS} = (\hat{X}^T \hat{X})^{-1} \hat{X}^T y, \quad (4)$$

where \hat{X} are the predicted values obtained from regressing the endogenous variables on the exogenous and instrumental variables and y is the vector of the dependent variable. This procedure ensures that the resulting estimates are consistent even when the exogenous variables are correlated with the error term (Baltagi, 2008).

2.3. Three-Stage Least Squares Method

The Three-Stage Least Squares (3SLS) method is an extension of 2SLS to systems of simultaneous equations where the error components of different equations are correlated (Basu et al., 2018; Greene, 2003; Zellner & Theil, 1962). The procedure involves:

- Estimate individual equations using 2SLS to obtain predicted values for the endogenous variables (Wooldridge, 2011).
- Estimation of the covariance matrix of the residuals Ω between the equations according to the equation:

$$\Omega = E[\varepsilon\varepsilon^T] \quad (5)$$

where ε is the vector of error components for each observation. This matrix is estimated by iterative methods to include correlations between the errors in different equations (Baltagi, 2008).

- Combined estimation of the whole system of equations using the estimated covariance matrix. The resulting parameter estimation is given by:

$$\hat{\beta}_{3SLS} = (X^T \Omega^{-1} X)^{-1} X^T \Omega^{-1} y \quad (6)$$

where X is the matrix of explanatory variables, y is the vector of the dependent variable, and Ω represents the estimated covariance matrix of residuals (Judge et al., 1985; Greene, 2003).

2.4. Maximum Likelihood Method

The Maximum Likelihood Estimation (MLE) method is based on finding parameter values that maximize the likelihood of the observed data (Judge et al., 1985; Greene, 2003). For a system of simultaneous equations, the estimation is performed iteratively. The likelihood function is defined as:

$$L(\theta) = \prod_{i=1}^n f(y_i; \theta) \quad (7)$$

where $f(y_i; \theta)$ is the probability density for the observation y_i and θ is the parameter vector (Casella & Berger, 2002; Lehmann & Casella, 1998). Optimization is performed by maximizing a log-likelihood function:

$$\ln L(\theta) = \sum_{i=1}^n \ln f(y_i; \theta) \quad (8)$$

Iterative algorithms such as the Newton-Raphson or Fisher scoring method are used to find the values of the parameters θ (Nocedal & Wright, 2006). MLE allows parameter estimation in systems of simultaneous equations even when the variables have a complex covariance structure (Greene, 2003; Wooldridge, 2011).

3. Application

The proposed application (Pilná, 2024) implements the methods described above and allows users to analyze simultaneous equations based on data input. Key features include:

- Data upload: the user can upload data in CSV format containing the necessary economic variables.
- Calculation of coefficients: the application allows you to estimate parameters using OLS, 2SLS, 3SLS, and MLE.
- Results are presented in the form of tables containing coefficient estimates and diagnostic statistics.
- Data export: users can export results in CSV format for further analysis.

The application also includes components for working with large data sets, optimized calculations, and integration with external databases. This enables the application to meet a wide range of analytical requirements, from basic regression analysis to advanced econometric modeling.

4. Analysis and Results

4.1. Data Description

The Klein model is one of the classic macroeconomic simultaneous equation models that focuses on the interrelationships between key macroeconomic variables such as gross domestic product (GDP), consumption, investment, wages, and other economic indicators. It allows for the analysis of macroeconomic linkages and effective prediction of economic behavior (Klein, 1950; Greene, 2003).

The model consists of several simultaneous equations that describe the interdependence of the following variables: the consumption equation (9), the investment equation (10), the aggregate income equation (11) and the wage equation (12). Each equation in the model describes the causal relationships between economic variables and allows for predictions of the evolution of the economy based on historical data.

$$C_t = \alpha_0 + \alpha_1 Y_t + u_{1t}, \quad (9)$$

$$I_t = \beta_0 + \beta_1 Y_{t-1} + \beta_2 W_t + u_{2t}, \quad (10)$$

$$Y_t = C_t + I_t + G_t, \quad (11)$$

$$W_t = \gamma_0 + \gamma_1 Y_t + \gamma_2 T_t + u_{3t}, \quad (12)$$

where:

C_t is the consumption at time t ,

Y_t is the gross domestic product,

I_t are investments,

Y_{t-1} is lagged GDP,

W_t represents wages,

G_t is government spending,

T_t are taxes,

u_{1t}, u_{2t}, u_{3t} are error components.

The data in Table 1 present an analysis of the U.S. economy during the interwar period. It was originally published in "Economic Fluctuations in the United States, 1921–1941", a study that dealt with this very topic (Klein, 1950). For the purposes of this study, the values were obtained from the book "Econometric Analysis" (Greene, 2003).

The data table contains one row for each year of the respective column analysis, where each column has a meaning (Pilná, 2024):

- Year: this column contains the years 1920 to 1941.
- C (Consumption): represents total economic consumption in a given year.

- P (Corporate Profits): include the total profits of firms after deducting all costs.
- Wp (private wages): the wages that private firms pay their employees.
- I (Investment): includes expenditure on the purchase of new capital.
- K1 (Capital from the previous year): capital available in the previous year.
- X (Gross National Product): the total value of all goods and services.
- Wg (Government Wages): the salary paid by the government to its employees.
- G (Government expenditure): represents all government expenditure on the purchase of goods and services.
- T (Taxes): money collected by the government from households and firms.

Table 1. Data (Klein Model I)

Year	C	P	Wp	I	K1	X	According to	G	T
1920	39.8	12.7	28.8	2.7	180.1	44.9	2.2	2.4	3.4
1921	41.9	12.4	25.5	-0.2	182.8	45.6	2.7	3.9	7.7
1922	45	16.9	29.3	1.9	182.6	50.1	2.9	3.2	3.9
1923	49.2	18.4	34.1	5.2	184.5	57.2	2.9	2.8	4.7
1924	50.6	19.4	33.9	3	189.7	57.1	3.1	3.5	3.8
1925	52.6	20.1	35.4	5.1	192.7	61	3.2	3.3	5.5
1926	55.1	19.6	37.4	5.6	197.8	64	3.3	3.3	7
1927	56.2	19.8	37.9	4.2	203.4	64.4	3.6	4	6.7
1928	57.3	21.1	39.2	3	207.6	64.5	3.7	4.2	4.2
1929	57.8	21.7	41.3	5.1	210.6	67	4	4.1	4
1930	55	15.6	37.9	1	215.7	61.2	4.2	5.2	7.7
1931	50.9	11.4	34.5	-3.4	216.7	53.4	4.8	5.9	7.5
1932	45.6	7	29	-6.2	213.3	44.3	5.3	4.9	8.3
1933	46.5	11.2	28.5	-5.1	207.1	45.1	5.6	3.7	5.4
1934	48.7	12.3	30.6	-3	202	49.7	6	4	6.8
1935	51.3	14	33.2	-1.3	199	54.4	6.1	4.4	7.2
1936	57.7	17.6	36.8	2.1	197.7	62.7	7.4	2.9	8.3
1937	58.7	17.3	41	2	199.8	65	6.7	4.3	6.7
1938	57.5	15.3	38.2	-1.9	201.8	60.9	7.7	5.3	7.4
1939	61.6	19	41.6	1.3	199.9	69.5	7.8	6.6	8.9
1940	65	21.1	45	3.3	201.2	75.7	8	7.4	9.6
1941	69.7	23.5	53.3	4.9	204.5	88.4	8.5	13.8	11.6

4.2. Analysis

This dataset was then subjected to simultaneous econometric analysis using methods such as two-stage and three-stage least squares (2SLS, 3SLS) and maximum likelihood estimation (MLE) (Wooldridge, 2011; Greene, 2003). The aim was to obtain accurate estimates of the relationships between the variables and to test the validity of Klein's model (Klein, 1950). The practical application of the model allowed:

- Estimating the basic economic relationships between GDP, consumption, and investment (Klein, 1950).
- Assessing the role of fiscal policy, such as the impact of government spending and taxes on the economy.

- Finding wage dynamics in relation to economic growth.
- Simulating alternative scenarios of economic development based on various input parameters (Hušek, 1999).

4.3. Results

Table 2. Summary table of all results

Coefficients	OLS	OLS: Greene	2SLS	2SLS: Greene	3SLS	3SLS: Greene	MLE
alpha_0 (C)	14.4446	16.2	14.7305	16.6	12.7083	16.4	16.2366
alpha_1 (C)	0.1994	0.193	-0.1623	0.017	-0.1332	0.125	0.1929
alpha_2 (C)	0.0941	0.09	0.3408	0.216	0.642	0.163	0.0899
alpha_3 (C)	0.8304	0.796	0.8732	0.81	0.7697	0.79	0.7962
beta_0 (I)	13.6585	10.1	18.132	20.3	29.3338	28.2	8.3646
beta_1 (I)	0.4593	0.48	0.2441	0.15	0.0933	-0.013	0.5145
beta_2 (I)	0.2407	0.333	0.4139	0.616	0.5917	0.756	0.2256
beta_3 (I)	-0.1204	-0.13	-0.139	-0.158	-0.1974	-0.195	-0.0977
gamma_0 (W^p)	0.8395	1.5	0.8121	1.5	1.8344	1.8	-0.0659
gamma_1 (W^p)	0.4391	0.439	0.451	0.439	0.2374	0.4	0.4395
gamma_2 (W^p)	0.1371	0.146	0.1259	0.147	0.2736	0.181	0.1461
gamma_3 (W^p)	0.1081	0.13	0.1051	0.13	0.349	0.15	0.1302

After applying each method, we obtained the following key findings:

- OLS results: showed basic trends between variables, but due to the endogeneity of some variables, the results were biased.
- 2SLS and 3SLS: Provided more consistent and accurate parameter estimates by eliminating endogeneity bias.
- MLE: It yielded the most efficient estimates by taking into account the entire structure of the model and the probabilistic relationships between the variables.

Based on the resulting values in Table 2, each estimation method provides different results for the model parameters, which could be due to the other ability of these methods to address issues such as endogeneity and simultaneity in multi-equation models (Judge et al., 1985; Hansen, 1982). The OLS and MLE methods appear more stable, while the 2SLS and 3SLS methods show more variability, which may reflect their sensitivity to instrument selection and model specification (Hušek, 1999). Our analysis confirmed that the model describes economic relationships well. Still, it also showed some limitations, such as the need to account for structural changes in the economy and possible biases caused by the endogeneity of some variables.

5. Discussion

The results of each method show that the use of more advanced approaches such as 2SLS, 3SLS, and MLE is crucial for the analysis of simultaneous equations. While OLS provides fast and easy estimation, its results can be heavily biased due to endogeneity and correlated errors. In contrast, methods that address these issues provide deeper insights into the relationships between variables.

When applying the 3SLS, a strong correlation between investment and GDP was found, confirming the theoretical assumptions (Klein, 1950; Hušek, 1999). On the other hand, the MLE method revealed a finer structure of relationships that might otherwise have been overlooked. These results underscore the importance of careful choice of method when analyzing economic data.

The results of this study also show that econometric modeling should always be accompanied by thorough residual diagnostics and tests to assess the suitability of the chosen method. For example, heteroskedasticity and autocorrelation tests can reveal issues in the models that may lead to incorrect conclusions.

In future research, it would be interesting to expand the model to include additional macroeconomic variables, such as interest rates or foreign trade, and examine their impact using various estimation techniques. This could provide a more comprehensive picture of economic relationships and improve the accuracy of predictions.

Each method has its own advantages and limitations, making it crucial to select the appropriate one based on the specific objective of the analysis and the characteristics of the available data. A careful combination of economic theory, high-quality data, and suitable statistical tools is essential for obtaining relevant and reliable results.

6. Conclusion

Analysis of simultaneous equations using advanced methods such as 2SLS, 3SLS, and MLE provided consistent and efficient estimates of the relationships between key macroeconomic variables. The use of these methods has allowed us to overcome the limitations of the traditional OLS approach and gain a deeper understanding of the dynamics of economic systems. The results of this study can serve as a basis for further research and practical applications in macroeconomics.

The significance of this study also lies in the applicability of the methods in practice. In addition to academic research, the methods used in this study can have a direct impact on analyses conducted by central banks, government institutions, and research organizations. This analysis not only contributes to the theoretical understanding of economic models but also to their practical application in macroeconomic decision-making processes.

Overall, it can be concluded that the use of advanced methods for analyzing simultaneous equations provides new opportunities and deeper insights into macroeconomic processes. At the same time, it presents a challenge for further research and the application of these tools in real-world economic situations. This study thus not only provides valuable conclusions for theory but also specific recommendations for practice, making its results relevant to a broad audience in the field of economic decision-making.

Conflict of interest: none

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Detection of the Influence of Economic Indicators on Political Stability in the EU Countries

Tomáš ROSKOVEC, Jana KLICNAROVÁ, Jan FIALA and Ilona BERKOVÁ*

University of South Bohemia, České Budějovice, Czech Republic; troskovec@pf.jcu.cz; janaklic@fzt.jcu.cz; fiala@pf.jcu.cz; berkova@fzt.jcu.cz

* Corresponding author: berkova@fzt.jcu.cz

Abstract: This article examines the relationships between the political stability in selected European countries and selected economic indicators. We ask if the economic condition of the state can be used to predict the re-election or exchange of the government (political stability or instability). We pick several economic indicators and election results in a 30-year period in the main election in the states of the EU. Our goal was to design the prediction of election results based on the economy. However, by using correlation analysis, cluster analysis, and regression analysis by logistic regression, we verify only the connection between inflation and the change in national debt. Other indicators, such as GDPpp and unemployment and its change, surprisingly, do not influence voters enough. We conclude that in a 30-year period in the well-developed economies of the EU, economic factors are not strongly influenced by voters.

Keywords: political stability; political instability; economic voting; government change; prediction of election results

JEL Classification: O11; D72; C15

1. Introduction

The connection between political stability and economic situation and growth is well-documented (Hadley, 1899; Asiimwe, 2015). Political instability often reduces investments and economic growth, while economic failures can trigger government changes or unrest (Alesine et al., 1996). Our study measures the strength of this relationship and identifies economic factors influencing government stability, focusing on the EU over the past 33 years. We also explore which economic aspects governments can influence. This research builds on Žiška's (2023) thesis but applies advanced methods to derive new insights.

1.1. *The Influence of the Economy on Political Development*

Economic instability increases the likelihood of government collapse, reduces investments, and slows growth (Asiimwe, 2015). Stable democratic governance often requires a minimum level of economic development. Poor economic conditions can trigger leadership changes, perpetuating instability. Macroeconomic factors like unemployment and inflation are influenced by investments and government interventions, while microeconomic stability depends on market competition and freedom.

In conclusion, state leaders are familiar with the fact that voters see the economic situation as their responsibility, and a poor economy may endanger their political position. In some cases, the government may be exchanged even based on bad situations out of their control, such as an international crisis or unpopular monetary decisions of the national bank. Also note that this is not exclusive to democratic regimes, as even autocratic regimes aim to keep people satisfied by a functional economy to prevent unrest and revolutions.

1.2. The Influence of Politics on Economic Development

According to Przeworski et al. (2000), politics provides a key framework for economic development. Unlike other aspects, politics is at the center of the entire system of development and transformation of society.

All the laws, including taxation, are under the control of the politicians. Therefore, politics constantly interferes with the market situation and economy. Employment regulation, import and export regulation, and taxation levels can invite or deter investors. Investments in education and infrastructure can ease economic growth. On the other hand, factors like the monetary politics of national banks or international financial crises like inflation caused by the Russian invasion of Ukraine can marginalize the government's efforts. By controlling both spending and taxation, the government's responsibility is to control the national debt. In some cases, the government may financially support some industries, such as agriculture or green sectors across the EU, or relieve taxation for investors. These can decrease unemployment but are expensive in the long run, both in inflation and debt. In general, a typical decision made by the government to improve some aspect of the economy may hurt another element. Mueller (2003) presents how right-wing governments focus on lowering inflation while left-leaning focus on unemployment, as demonstrated in the case of presidents of the USA. However, governments lowering inflation also lower employment rates while lowering unemployment costs and spending and increases inflation.

One of the problems of a democratic government is that short-term effects are often a priority over long-term benefits. This may lead to increasing spending in order to appease voters in an unsustainable way. However, such policies have to be corrected at some point (Lefkofridi, 2014). On the other hand, short-term harm could lead to long-term benefits, such as abandoning unprofitable and outdated industries (Jones, 2009), leading to short-term unemployment. In extreme situations, the government's lack of decisiveness may lead to hyperinflation or even national bankruptcy.

2. Literature Review

Scientists from all over the world have been interested in the topic of the economy's influence on politics with intense focus since the middle of the last century. The relationship between politics and economics has also become a regular subject of interest for various international institutions (e.g. World Bank, 2006).

Previous research in this area has produced many results, but they are often ambiguous and lack general applicability across countries (e.g. Anderson, Mendes & Tverdova, 2004; Nadeau, Lewis-Beck & Bélanger, 2013). Economic voting is highly country-specific, varies

over time, and is influenced by a wide range of factors (e.g. Lewis-Beck & Stegmaier, 2000; Aisen & Veiga, 2010; Reidy, Suiter & Breen, 2018; Lewis-Beck, Nadeau & Elias, 2008). For instance, high GDP growth fosters economic prosperity and employment, often boosting government popularity and reducing the likelihood of government change. Conversely, GDP decline typically signals economic recession, rising unemployment, and lower living standards, leading to voter dissatisfaction and increased pressure for change. Similarly, falling unemployment and an improving labour market contribute to a positive perception of the government, whereas price stability and low inflation enhance trust in economic management, reducing calls for government turnover. However, as summarized by Lachat (2009), poorly managed fiscal policies—such as budget deficits, rising debt, and underfunded public services—can fuel discontent and demands for change. Notably, recent research by Mutz and Mansfield (2024) suggests that inflation, despite its broader economic significance, does not always play a decisive role in shaping voter behaviour.

Research on the relationship between political and economic variables influencing voter attribution of responsibility for economic conditions is a frequent topic (Duch & Stevenson, 2008; Fortunato & Stevenson, 2013; Alesina et al., 1996; Evans & Andersen, 2006, etc). Many studies highlight unemployment as the most significant indicator of economic voting (Bengtsson, 2004; Lewis-Beck & Mitchell, 1990; Nannestad & Paldam, 1997; Sanders, 2003). Education also plays a role, with Bartels (1996) and Tillman (2011) showing its impact on government change. Voter perceptions of the EU's economic influence have also been studied. Costa Lobo & Lewis-Beck (2012) found that national economic voting declines when voters attribute economic responsibility to the EU. Bartkowska & Tiemann (2015) emphasized the role of economic voting in short-term vote shifts and electoral volatility in European Parliament elections. In coalition politics, Van der Brug et al. (2007) noted that voters primarily blame the Prime Minister or Finance Minister for poor economic performance, using these roles as key shortcuts for attributing responsibility.

Political instability, as defined by Alesina et al. (1996), refers to the tendency to change governments through constitutional or unconstitutional means. Masayuki (2011) has shown that political instabilities significantly hamper economic growth. Studies show it hampers economic growth (Masayuki, 2011), while in Romania, Radu (2015) analyzed its specific effects. Yakubu et al. (2020) argue that stability can also undermine long-term growth. Political uncertainty discourages investment and savings, as risk-averse agents delay initiatives or invest abroad, and foreign investors prefer stable environments. On the other hand, low economic growth increases government instability. A large amount of empirical literature has shown that in industrial democracies, the chance of re-election of incumbent governments depends on the growth rate immediately before the election. In non-democratic countries, low growth increases popular discontent, creates incentives for anti-government activities, and can increase the likelihood of coups. As it turns out, the government's fall can be caused by both endogenous (incompetent government) and exogenous factors (world economic decline). Alesina et al. (1996) show that in countries and periods with a high propensity for government collapse, economic growth is significantly lower than otherwise.

Londregan and Poole (1990) analyzed data from 121 countries (1950–1982) and found that economic well-being significantly impacts the likelihood of coups. Anderson (2000) showed that voter behavior is influenced by the interaction between political context and economic perceptions. In Scandinavia, Larsen (2016) demonstrated that economic conditions shape electoral support for prime ministerial parties, underscoring the importance of economic voting. Conversely, Dassonville and Lewis-Beck (2019) found that economic voting in Western Europe is stable over time and not strongly tied to current economic conditions. Larsen (2021) adds that experienced governments are less affected by economic fluctuations than inexperienced ones. As summarized by Lewis-Beck and Whitten (2013, p. 393): “When the economy is doing well, voters reward the government, but when the economy falters, they punish it.”

3. Data

We collected data on economics and elections for the past 33 years in 27 current member states of the EU. Note that at the beginning of our measured interval, some of these countries were not members of the EU. The choice of data is to pick countries in similar situations for the same historical period so the process of election and economic is comparable. We observed only the main election, which has the greatest impact on the country's government. In most states, it is the parliament election that leads to establishing a government. We opt for presidential elections in states with big presidential power (Cyprus, France). After cleaning, we analyse 186 data, 82 without the change of government (0), 104 with the change (1). The impact of Covid on the economic results of countries was not taken into account because the pandemic affected all countries more or less comparably. It would be of interest to study the influence of pandemic and restrictions on election and economics by themselves, but our data set would be too small for method we apply.

3.1. *Selected Economic Indicators*

We opt for 4 indicators in two forms: one is the absolute value, and the other is the derivative, i.e. 8 factors. These are Debt to GDP of the country, GDP per capita (GDPpp), Inflation, Unemployment, Change in Debt (to GDP), Change in GDPpp, Change in Inflation, and Change in Unemployment. The change represents the change in the years before the elections. Variables Change in Debt (to GDP), Change in Inflation, and Change in Unemployment are naturally in %. The last Change variable Change in GDPpp is the difference divided by the absolute value, so it is also in %. The indicators that appear most frequently in all major publications on this issue were selected. In general, other indicators can be involved, but as the economic situation is complex and factors influence each other, these four fundamental indicators may capture the country's condition in the view of the typical voter. Also, finer indicators may influence part of the population, but to influence the whole process, we need a factor influencing the significant number of voters.

3.2. Data about Politics, Data about Economic Indicators, Data Editing and Cleaning

Note that we have to exclude a lot of data, restricting only to elections with the possibility of change or re-election results. First, we consider only the elections with an interval of at least two years after each other, as one year of government does not strongly influence the economy, and such a fast election would probably be more influenced by other factors. Also, suppose the incumbent government or president is not partisan, for example, holding the office for a short term after a political crisis. In that case, we exclude the election, as no re-election option exists. This is also true for the first democratic elections in the countries, as there is a fresh start of competition and no possibility of re-election. We also exclude the elections that are suspicious of a coup, although this is exceptional in our setting. Finally, we exclude elections in the most extreme economic situations, such as the post-soviet republics with hyperinflation in the early 1990s, as we wish to observe elections with stable situations and economies. In the end, we analyse 209 elections between 1990 and 2023.

We have to set the value of the elections to 0 or 1 for each election, 1 for change, and 0 for the incumbent's re-election. This is hard in parliament systems with a government consisting of a coalition of different parties, so we have to interpret ambiguous cases. We consider no change if the coalition forming the government stays but the prime minister is changed. If the government has minor changes and the prime minister stays, we consider no change. But if either the majority of the coalition is changed or the minority and the prime minister is changed, we consider it the change. We fully understand that cases are specific and that a finer scale could be better, but this model is practical for statistics and also seems to capture the spirit of our question: Is the result of this election a change?

4. Methodology

Based on our data collection, we aim to decide if there is any relationship between economic variables and the results of the elections. More precisely, we are interested in the possible prediction of election results, in the sense of continuity of so far government or changing it. Based on the literature review, we decided to employ logistic regression.

Before doing so, we need to check the data collection and assumptions of the method. We also apply cluster analysis to explore the data in more detail.

4.1. Data Cleaning

First, we must check the data collection; we begin with a visual control. If we look at each variable separately, we can see three outliers. The first one has inflation 121, when all other observations are between -1.3 and 22, the second one has a change of unemployment rate 9.8, when the rest are between -6 and 1, and the last one has the change of debt 4.7 where the others are between -0.35 and 1. Therefore, we deduce that the data contains outliers that must be removed before running statistical analysis. The data set includes probably correlated eight variables, but the dependence among them is not supposed to be too strong. Hence, we look at the data as vectors and remove observations out of the range $(Q_1 - 6IQR, Q_3 + 6IQR)$ under at least one variable, where Q_1 and Q_3 are quartiles and interquartile ranges (IQR ; $IQR = Q_3 - Q_1$). The choice of value of 6 is a compromise, if we have only one variable, we

choose usually 1.5; here we have 8 variables, so we had to use a higher number. (In case of using 1.5, we remove too many observations due to eight variables.) If we apply such an approach, we identify five outliers, where three of them are the same as the ones mentioned above, and there are only two new ones. Hence, we have decided to apply such a data cleaning.

4.2. Correlation Analysis

Before any further analysis, we check the correlation among our examined variables. We need to check that there is no strong correlation, which means that we chose different variables, and it gives a sense to involve all of them in the analysis. According to general assumptions, all variables should follow a normal distribution in each country. Therefore, the Pearson correlation coefficient could be applied. But, as we have observed the variables through different countries, we have observed variables that are a mix of normal distributions. Hence, we apply Spearman correlation coefficients.

4.3. Cluster Analysis

We employ cluster analysis for a more detailed exploration of our data set. Our idea is to apply cluster analysis to the data without providing information about possible changes in the government. We aim to cluster individual observations and then look at whether we have more or less situations with the change of the government in some clusters. In the first step, we normalize the data. Since we plan to use a K-means method, we normalize the data so that each variable is a unit vector. First, we apply hierarchical clustering to get the basic information of possible clustering, and based on these results, we decide to split into four clusters by the K-means method.

4.4. Logistic Regression

Our analysis aims to decide if economic characteristics impact election results in the sense of the change of the government. Hence, we apply logistic regression, where the dependent variable is a change in the government, and for the independent ones, we choose economic characteristics.

The logistic model predicts the probability of government change under given economic factors. The formula is as follows:

$$P[Y(X) = 1] = \frac{\exp(\beta'x)}{1 + \exp(\beta'x)} \quad (1)$$

Where Y is the change of the government, and the vector x is a vector of economic variables. We estimate the parameters β . Hence, we may predict, based on economic variables, the probability of a change in government.

The logistic regression assumptions are fulfilled since the dependent variable is binary, we removed outliers, and multicollinearity is not our case. (According to correlation analysis, we also checked it using variance inflating factors.)

First, we estimate the parameters of logistic regression using all considered variables. If the model is significant, we check the significance of each factor and construct the model based only on significant factors. Then, we check by Likelihood ratio test if we can simplify the whole model to the simpler one or the simpler one to the null model.

Finally, we verify the quality of our model by the so-called Confusion Matrix, where we compare the real data with predicted ones; in more detail, we summarize cases where the prediction is true positive, false positive, true negative, and false negative. The better model has a higher rate of true results than the false ones.

The other possibility for verifying our model is to construct the ROC function. The ROC function shows the dependence of the true positive rate on the false positive rate. Therefore, the better model has a larger area between the ROC function and function $y = x$.

5. Results

The following chapter presents the results of the correlation analysis, cluster analysis, and logistic regression. These analyses were employed to model government changes based on various economic indicators. Through these methods, we aimed to identify patterns and relationships that could explain political shifts, offering insights into the potential influence of economic factors on government stability.

5.1. Correlation Analysis

This section analyses the interdependencies between the selected economic indicators using a correlation matrix. The indicators examined include Gross Domestic Product per Capita (GDPPP), Inflation rate, Unemployment rate, Government Debt, and their annual changes.

The correlation matrix, showing the Pearson correlation coefficient values between the indicators, is presented in Table 1 below. Statistically significant correlations are noted by *.

Table 1. Correlation matrix for selected variables (economic indicators)

	Inflation	Debt	GDPPP	Unemployment	Inflation change	Debt change	GDPPP change	Unemployment change
Inflation	1	-0.2068*	-0.4097*	-0.1310	0.2075*	-0.1241	0.2245*	0.0053
Debt	-0.2068*	1	0.1689*	0.1593*	0.0429	0.0193	-0.1752*	0.0588
GDPPP	-0.4097*	0.1689*	1	-0.3296*	0.2835*	-0.0384	-0.2772*	0.1223
Unemployment	-0.1310	0.1593*	-0.3296*	1	-0.2149*	0.1055	-0.0402	0.0794
Inflation change	0.2075*	0.0429	0.2835*	-0.2149*	1	-0.2060*	-0.0308	-0.1150
Debt change	-0.1241	0.0193	-0.0384	0.1055	-0.2060*	1	-0.3134*	0.4245*
GDPPP change	0.2245*	-0.1752	-0.2772*	-0.0402	-0.0308	-0.3134*	1	-0.3292*
Unemployment change	0.0053	0.0588	0.1223	0.0794	-0.1150	0.4245*	-0.3292*	1

The correlation analysis showed several significant relationships between the macroeconomic variables studied. None of the indicators showed full dependence on the others. Indicators describing year-on-year change showed a lower degree of correlation. The

least significant indicators were the year-on-year change in unemployment and the year-on-year change in indebtedness. In contrast, the GDPPPP indicator showed a significant degree of correlation with other economic indicators. Specifically, there was a negative relationship between GDP per capita and the unemployment rate, suggesting that more economically advanced countries generally have lower unemployment, which confirms Okun's law. The negative relationship between GDPPPP and inflation was also evident, indicating the impact of price instability on economic performance. Negative relationships were identified between inflation and debt, where higher inflation may contribute to a reduction in the real value of debt. Interestingly, the link between inflation and unemployment is insignificant, suggesting that theoretical models such as the Phillips curve may not have universal validity in long-term practice.

5.2. Cluster Analysis

Next, a cluster analysis was conducted to identify patterns among economic indicators in relation to government change. A graph showing the average of the defined clusters is shown below.

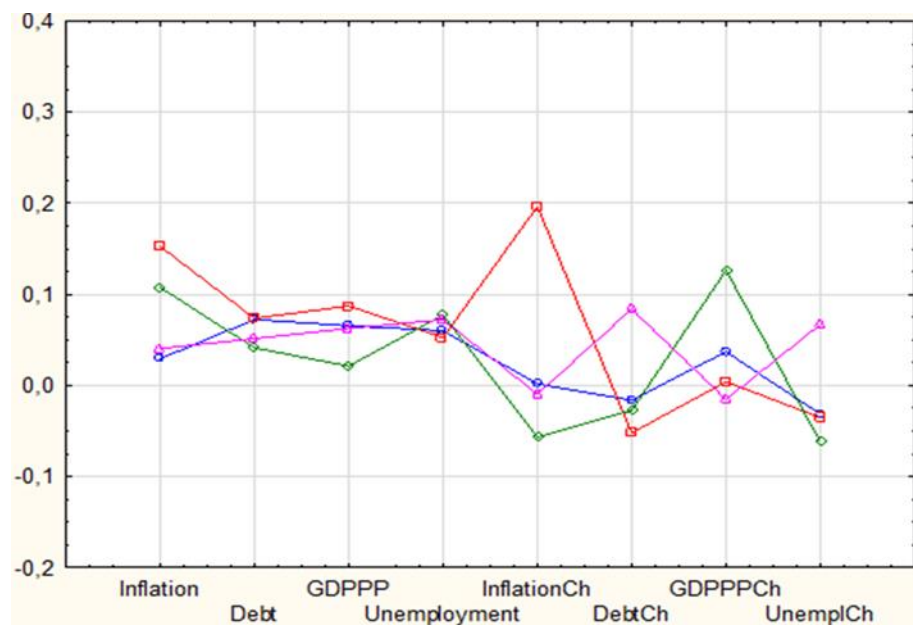


Figure 1. Cluster analysis of the means of all clusters

Based on the analysis, four clusters were identified with the following distribution:

- Cluster 1 (blue line): Contains 47 cases without government change (0) and 41 cases with government change (1).
- Cluster 2 (red line): Contains 4 cases without government change (0) and 11 cases with government change (1).
- Cluster 3 (green line): Contains 16 cases without a change of government (0) and 32 cases with a change of government (1).
- Cluster 4 (pink line): Contains 13 cases without a change of government (0) and 15 cases with a change of government (1).

Each cluster was analysed regarding the average values of economic indicators, revealing intriguing patterns. Notably, Cluster 2 stood out, with a significant majority of cases involving government changes (11 out of 15 observations). This cluster is characterized by markedly higher inflation rates, greater fluctuations in inflation, and smaller changes in debt levels compared to the average values in other clusters.

Cluster 3 also showed a higher proportion of government changes (32 out of 48 observations). Like Cluster 2, this group exhibited high inflation rates; however, unlike Cluster 2, year-on-year changes in inflation were relatively low. Apart from a lower GDP per capita (GDPPP) level compared to other clusters, this group appeared relatively stable in other economic aspects.

The remaining clusters did not show a clear dominance of cases with or without government changes. In these clusters, the distribution of outcomes was more balanced, and no specific economic characteristics emerged as significantly distinct.

One notable trend observed across the analysis was a higher tendency for government changes in economically less developed countries, consistently exhibiting lower levels of GDP per capita. This suggests that economic underperformance might be linked to greater political instability.

5.3. Logistic Regression

Since our study aims to detect if some of our variables impact the results of the elections in the sense of the possible change in the government, we search for the model of how our variables influence the variable Change. We apply the logistic regression model, where the dependent variable is the variable Change. Economic indicators that could affect this process, namely Inflation, Debt, GDP per capita, Unemployment, and their changes, were used as independent variables.

After conducting the analysis and applying backward selection, only two variables—Inflation and Change in Debt—were found to have a statistically significant impact on the probability of a government change. Other indicators were not significant and were excluded from further analysis. Their insignificance could stem from various factors, including the complexity of voting behaviour (influence of non-economic factors, short-term vs. long-term effects), the nature of the indicators (e.g., changes in GDP per capita may be less noticeable to voters, unemployment rates do not affect all demographics), as well as voters' expectations, selective perceptions, and other contextual factors.

The resulting model, defined in Table 2, showed that the p-values of the two key variables (Debt Change and Inflation) are statistically significant (noted by *), confirming their effect on the probability of government change.

These results suggest that a deterioration in economic conditions, especially in the form of high inflation or significant changes in public debt, can substantially impact political stability. In such situations, political parties often face a loss of voter confidence and the risk of electoral defeat. This trend is more pronounced in less economically developed countries, where governments change more frequently than in more developed countries. Thus, an increment of debt or inflation is a significant risk for an incumbent government.

Table 2. Logistic model with Inflation and Debt Change variables.

	Coefficient	P-value
Intercept	-0.1525	0.4818
Inflation	0.1209	0.0174*
Debt Change	4.9351	0.0030*

We then conducted a Likelihood Ratio Test (LLR) to compare the full model and our proposed model with these two variables. The test result showed that the model with only two variables (Inflation and Debt Change) is appropriate because the p-value of the test is 0.15, which means that the hypothesis of equivalence of the models cannot be rejected, and the unnecessary variables can be simply omitted.

Another test, comparing the model with two variables and the null model (without any independent variables), showed a p-value of 0.001, which means that our model is statistically significant and provides meaningful predictions.

To assess the quality of the model, we calculated its accuracy using the confusion matrix. The result showed that the model correctly predicted 63 % of the cases. If we predict a change based on our results, our estimate is 65 % successful; if we predict that no change will occur, the success rate of our estimate is 59 %.

Finally, we evaluated the quality of the model using the ROC curve (Figure 2). The curve was located in the upper half of the first quadrant, indicating that the model has the ability to discriminate well between cases with and without government change. A larger area between the ROC curve and the diagonal line $y = x$ indicates better model prediction ability.

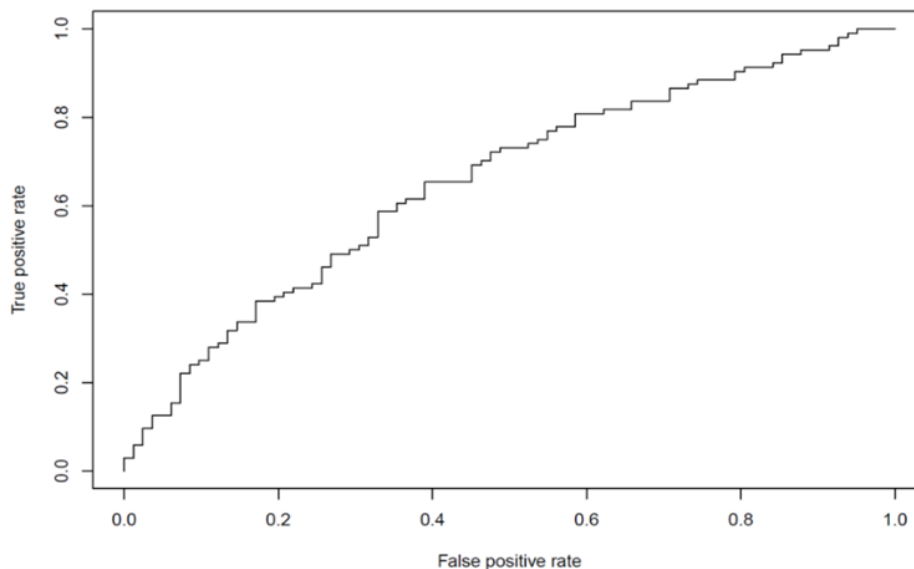


Figure 2. ROC curve

6. Discussion and Conclusions

In the paper, we investigated and statistically verified the influence of selected economic indicators on the political stability of selected states of the EU in the past 33 years. Political stability is defined as no change in government during an election; it means that the incumbent government stays in power or the governing coalition changes only marginally.

We use correlation analysis tools, Likelihood Ratio Test (LLR) and logistic regression, a model with eight economic indicators for testing.

The results of our analysis show that economic problems such as high inflation and rising public debt are associated with a higher probability of a change in government. Countries facing negative economic trends such as high inflation, low purchasing power, and irresponsible fiscal policy are more likely to have voters seeking new political representation. These economic problems often lead to dissatisfaction among the population, who perceive the government as unable to manage the economy effectively. However, the connection is not as strong as expected, and many factors do not influence voters enough. It is concerning that increasing GDP does not lead to a higher chance of re-election despite clearly improving well-being. Also, Žiška (2023) uses different data-cleaning methods and concludes that unemployment is the only factor affecting re-election (subtly). In conclusion, it is not possible to predict the outcome of elections based on the economics of the current EU countries alone, as voting behaviour is a complex process. Future research could include qualitative data such as opinion polls on perceptions of the economy, the effects of political campaigns, etc. Furthermore, research could be extended to regional or economic differences between countries. As authors, we are aware of the limitations of our research, which may be of different nature. One of them may be the inclusion of only economic factors and thus the omission of, for example, demographic, cultural, etc. factors. Another limitation may be geographical limitations, data bias from different research methodologies, or voter behaviour.

Conflict of interest: none

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Cost-Saving Potential of AI-Driven Solutions in Radiology: Analyzing Workflow Efficiency and Salary Reductions

Marek ŘEHOŘ^{1*} and Daniel KVAK²

¹ Prague University of Economics and Business, Prague, Czech Republic; marek.rehor@vse.cz

² Carebot s.r.o., Prague, Czech Republic; daniel.kvak@carebot.com

* Corresponding author: marek.rehor@vse.cz

Abstract: This study evaluates the economic and operational impact of implementing AI-driven solutions in radiology, focusing on workflow optimization and cost reduction in the evaluation of low-risk chest X-rays. Building on previous findings that demonstrated a 62.82% reduction in reporting time with AI-generated reports compared to manual methods, this study expands the analysis to quantify the potential financial benefits. A cost-minimization analysis indicates that AI adoption could result in annual savings of up to 127,228 CZK per radiologist. For an average facility with 5.45 radiologists, the estimated total annual savings could reach 693,396 CZK. The study highlights AI's role in alleviating radiologists' workload by automating routine evaluations, enabling them to focus on complex diagnostic tasks. Furthermore, the financial feasibility of AI implementation was assessed across various salary levels and facility sizes, demonstrating its scalability and adaptability in radiological workflows. Future research should explore the long-term impacts on diagnostic quality, resource allocation, and healthcare system sustainability.

Keywords: artificial intelligence; radiology; workflow efficiency; cost savings; chest X-rays; diagnostic automation

JEL Classification: I10; I15; O33

1. Introduction

Effective management of personnel costs represents a critical challenge for healthcare facilities, especially as they strive to balance increasing demands for high-quality care with limited financial resources. Personnel costs often account for the largest share of healthcare expenditure, underscoring the need for efficient and innovative strategies to optimize workforce utilization without compromising patient outcomes (Figueroa et al. 2019; Qin et al., 2023). A shortage of qualified personnel, the coordination of specialized multidisciplinary teams, and the challenges of managing factors like stress, burnout, job dissatisfaction, and high staff turnover emerge as significant barriers to achieving the high standards of performance and quality in patient care expected by society (Herrera et al., 2023).

The ongoing human resource crisis in healthcare further exacerbates the need for innovative solutions to optimize workforce utilization and manage rising personnel costs. Globally, the shortage of healthcare workers, coupled with the aging workforce and

increasing prevalence of chronic illnesses, has placed immense strain on healthcare systems. Artificial intelligence (AI) offers a promising avenue for addressing these challenges by enhancing efficiency and reducing the administrative and diagnostic burdens on healthcare professionals. While AI is not intended to replace caregivers, its ability to support tasks such as routine evaluations and data analysis enables healthcare providers to focus their expertise on complex cases, ultimately improving patient outcomes and operational sustainability (Meskó et al., 2018; Sengupta et al., 2018).

Radiologists, as essential contributors to diagnostic processes, account for a significant portion of healthcare expenditures. This article focuses on the potential for reducing these expenditures through the implementation of advanced automation technologies, specifically AI-driven solutions for low-risk chest X-ray (CXR) evaluations. In recent years, artificial intelligence (AI) has begun to transition from research settings into clinical practice, where its potential to enhance efficiency and reduce costs is increasingly recognized. AI has shown promise in automating routine tasks, such as the evaluation of negative chest X-rays, which often constitute a substantial portion of radiologists' workloads. By assisting with or automating these routine evaluations, AI can free radiologists to focus on more complex cases requiring their expertise, thereby improving workflow efficiency and addressing systemic challenges such as radiologist shortages (Schalekamp et al., 2024).

AI has the potential to significantly enhance the accuracy of radiological examinations by automating routine tasks such as image classification and segmentation, reducing errors caused by fatigue and improving workflow efficiency. However, it cannot replace the expertise, intuition, and complex decision-making of human physicians, who integrate clinical context and advanced knowledge to deliver personalized care. AI should be viewed as a complementary tool that supports radiologists, allowing them to focus on critical diagnostic and patient-centered tasks (Sengupta et al., 2018).

Artificial intelligence (AI) has the potential to greatly enhance the accuracy of radiological examinations by automating routine tasks such as image segmentation and abnormality detection, reducing errors and improving workflow efficiency. However, while AI excels at processing large datasets and recognizing complex patterns, it cannot replace the expertise, clinical judgment, and nuanced decision-making of radiologists. Instead, AI should be seen as a supportive tool that complements their work, allowing them to focus on critical diagnostic and patient-centered tasks that require human insight and empathy (Hosny et al., 2018).

The economic implications of integrating AI into clinical workflows are particularly relevant as healthcare systems worldwide face rising costs and workforce constraints. Demonstrating the cost-saving potential of AI is essential for encouraging its broader adoption. Evidence suggests that AI can significantly reduce the time and resources required for routine diagnostic tasks, thereby alleviating some of the financial pressures on healthcare providers. For instance, studies have indicated that AI-driven systems can cut the time spent on routine evaluations by over 60%, contributing to substantial savings in personnel costs and enabling more effective allocation of resources (Řehoř et al., 2024).

This study aims to quantify the economic benefits of implementing AI-driven solutions for the evaluation of negative chest X-rays, with a focus on cost savings and workflow optimization. By building on prior research, it seeks to provide a detailed assessment of how AI can support healthcare facilities in delivering high-quality care while managing costs effectively. This study uses outcomes from article focused on reduction of time by using AI-generated reporting method compared with manual reporting of low-risk chest x-ray images.

2. Methodology

2.1. Reduction of Time Using AI-Generated Reporting

Study from 2023 by Řehoř et al. compared three methods for evaluating low-risk chest X-rays: manual reporting, template-based reporting, and AI-generated reporting. Manual reporting, which relies on free-text documentation, was the most time-consuming, with average reporting times ranging from 70.8 to 96.4 seconds per study. Template-based reporting, utilizing structured fields to streamline documentation, reduced the average time by 53.93%, achieving reporting times of 32 to 48.8 seconds per study. AI-generated reporting proved the most efficient, with average times of 27.7 to 33.8 seconds per study, representing a 62.82% reduction compared to manual reporting.

The results highlight the potential of AI to significantly enhance workflow efficiency in radiology, particularly for routine low-risk cases. This study is using the reduction as an input for the analysis.

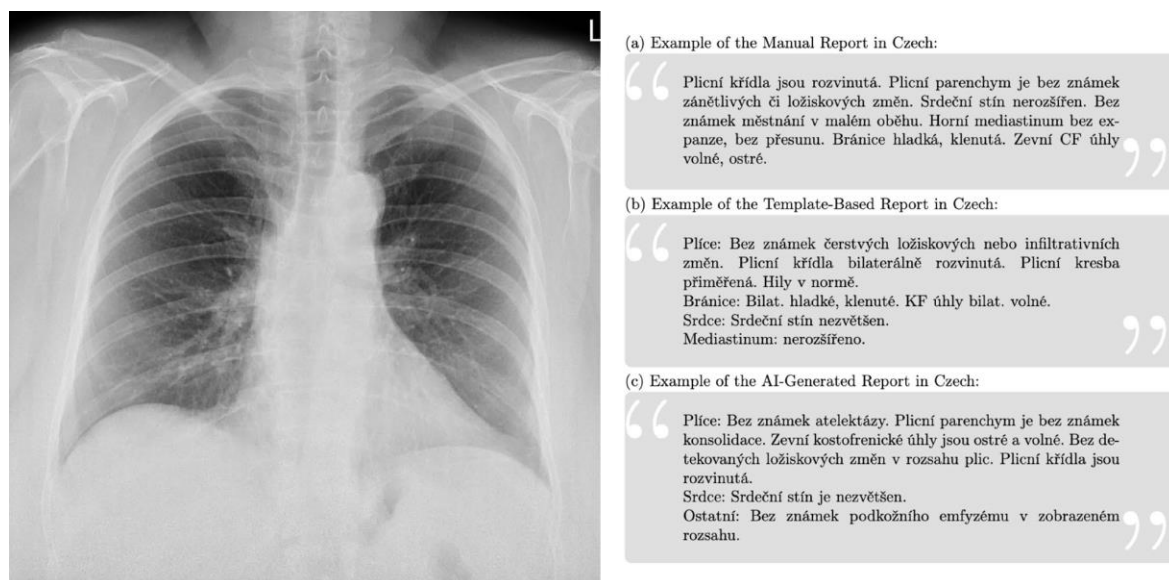


Figure 1. Comparison of reporting types for low-risk chest X-rays across three methods, data adapted from Řehoř et al. (2024)

2.2. Salaries and Workload of Radiologists in the Public Sector

According to data from the Czech Statistical Office (ČSÚ), the gross monthly salary of radiologists in the public sector in 2023 ranged between 78,670 CZK (1st decile) and 189,780 CZK (9th decile). This indicates significant variability in salaries depending on

experience, specialization, and other factors. The estimated average salary is approximately 134,000 CZK (Český statistický úřad, 2024).

In terms of workload, radiologists in the public sector were paid for an average of 191.5 hours per month in 2023. This corresponds to an estimated hourly wage of around 700 CZK. The high level of remuneration reflects both the demanding nature of radiology as a medical specialty and the extensive expertise required for the role (ČSÚ, 2024).

These statistics, sourced from the Czech Statistical Office, highlight the critical importance of radiologists within the healthcare system and provide insight into their professional compensation in the public sector. This information was used for purposes of analysis in this study.

Table 1. Monthly salaries of radiologists in the public sector (2019–2023)

Year	Salary	
	1st decile (CZK)	9th decile (CZK)
2019	58,689	129,996
2020	66,968	138,494
2021	74,631	155,717
2022	78,089	184,246
2023	78,670	189,780

2.3. Distribution and Workload of Radiologists in Healthcare Facilities

According to the 2021 report from the National Health Information System (NZIS), radiologists play a crucial role across a wide range of healthcare facilities in the Czech Republic. The report identifies several key types of institutions where radiologists are expected to be actively engaged. These include university hospitals (11 facilities), specialized hospitals (9 facilities), follow-up care hospitals (20 facilities), psychiatric hospitals (5 facilities), general hospitals (126 facilities), large outpatient centers (69 facilities), and small outpatient centers (52 facilities). In total, there are 292 facilities where radiological services are essential for accurate diagnostics and patient care.

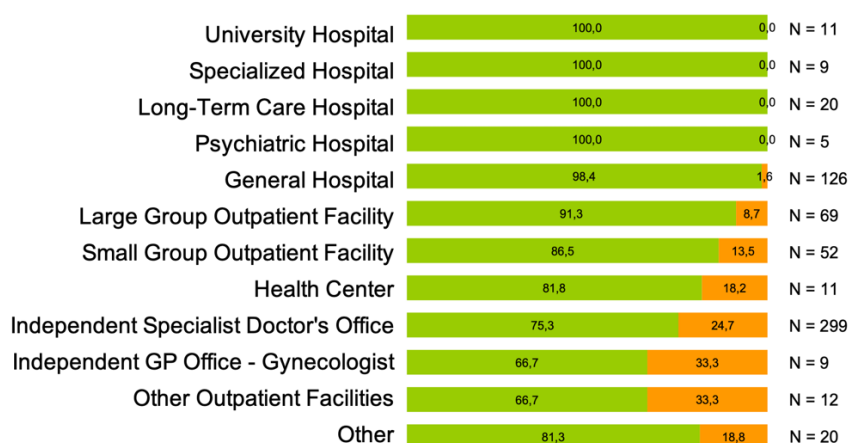


Figure 2. Healthcare facilities included NZIS 2021 report

The data further highlights the overall availability of radiologists in the healthcare system. As of 2020, there were 1,592 radiologists employed in the country. When distributed

across the identified facilities, this results in an average of 5.45 radiologists per institution. This number reflects the substantial demand for radiological expertise across various levels of medical care, from high-capacity university hospitals to smaller outpatient settings. The distribution indicates that while some larger institutions may have access to more specialized staff, smaller facilities might face challenges in maintaining sufficient coverage and expertise (Ústav zdravotnických informací a statistiky České republiky, 2021).

Radiologists are essential in diagnosing a wide range of medical conditions, including orthopedic injuries, respiratory diseases, and oncological conditions. Their presence in various medical institutions is critical to ensuring timely and accurate diagnoses. The rising demand for imaging services, driven by an aging population and the increasing prevalence of chronic diseases, highlights the need for strategic workforce planning in the field of radiology.

2.4. Radiologists' Workload and Negative Findings on Chest X-Rays

In routine clinical practice, a significant proportion of chest X-ray interpretations involve studies classified as having no significant findings. Research by Keski-Filppula et al. (2022) indicates that approximately 50% of chest X-rays are identified by radiologists as negative, containing no detectable pathology. This aligns with findings from various studies conducted in both primary care and hospital settings, where radiologists frequently evaluate imaging to rule out abnormalities rather than confirm a suspected diagnosis. This number was used for purposes of this study as a ratio of radiologist's work spend by evaluating non suspect images with no findings.

The high prevalence of negative findings highlights the substantial workload involved in reviewing and reporting chest X-rays, especially in high-throughput environments. This workload is compounded by the necessity to maintain diagnostic accuracy and ensure no critical findings are overlooked. Consequently, this raises the potential for implementing automated triaging systems, such as artificial intelligence (AI), to streamline workflows. AI systems can reliably identify studies without significant findings, allowing radiologists to focus on complex cases requiring their expertise (Keski-Filppula et al., 2022).

Such advancements not only have the potential to improve resource allocation but also address challenges associated with growing imaging volumes and radiologist shortages in many healthcare systems. Future research should explore how AI-based systems can be integrated into existing workflows without compromising diagnostic quality or patient safety.

2.5. Analysis of Lung Examinations in Radiology

According to the data presented in the 2021 Radiology Bulletin, lung examinations constitute a significant proportion of all diagnostic procedures. Out of a total of 10,067,200 radiological examinations (excluding dental procedures), 2,535,900 were focused on pulmonary imaging. This statistic underscores the high demand for lung diagnostics, which can be attributed to various factors, including the increasing prevalence of respiratory diseases, the impact of environmental conditions, and the ongoing need for early detection

and monitoring of conditions such as pneumonia, chronic obstructive pulmonary disease (COPD), and lung cancer (Státní úřad pro jadernou bezpečnost, 2021).

The report further suggests that the widespread utilization of radiological techniques such as chest X-rays and CT scans plays a crucial role in providing timely and accurate diagnoses. The emphasis on lung examinations reflects the evolving landscape of healthcare priorities, where respiratory health remains a major concern. Moreover, the COVID-19 pandemic has likely contributed to an increased focus on lung imaging, as healthcare providers continue to monitor the long-term effects of the virus on respiratory function.

In conclusion, with 2,535,900 lung examinations conducted annually, representing 25.19% of the total non-dental radiology workload, pulmonary diagnostics continue to play a critical role in modern healthcare. This trend calls for continued advancements in imaging technology and enhanced diagnostic capabilities to support healthcare professionals in delivering effective patient care.

Table 2. Numbers of X-ray examinations in Czech Republic in 2021

Category	X-ray Examination	Number of Examinations (thousands)
Radiography	Cervical spine	385.9
	Lungs	2,535.9
	Thoracic spine	270.7
	Lumbar spine	565.2
	Abdomen	352.7
	Pelvis and hip joints	695.7
Mammography	Diagnostic mammography	103.6
	Screening mammography	389.7
Dental X-ray	Intraoral X-ray	5,139.6
	Panoramic dental X-ray	1,463.2
Other radiography		4,767.8

2.6. Study Design

The economic model, designed to comprehensively analyze and quantify the financial and time-saving benefits of implementing AI-assisted solutions in medical imaging workflows, was developed through the following steps:

- Time Rection Data Collection: Data from a study by Řehoř et al. from 2024 focused on the time efficiency of the three CXR processing methods were utilized. Time reduction by using AI-generated reporting is 62,82 %.
- Costs for Economic Modeling:
 - Radiologists' Workload Allocation: According to the latest data, an average of 25.19% of a radiologist's time is dedicated to evaluating lung or chest X-rays. This significant portion highlights the emphasis placed on pulmonary diagnostics within the overall workload.
 - Staffing per Facility: With an average of 5.45 radiologists per healthcare facility, the distribution of radiology professionals ensures coverage across multiple diagnostic areas, with lung examinations representing a major focus of their work.

- Cost Savings from Negative Cases: Additional insights indicate that negative X-rays account for 50% of processed images. Given the updated average radiologist salary of 700 CZK/hour, the calculated cost savings reflect 62.82% of the time spent on processing negative cases. These savings are projected on a monthly and annual basis, offering valuable data for financial planning.
- Cost-Minimization Analysis (CMA): CMA was applied to evaluate the financial impact of implementing AI methods compared to traditional practices.
- Sensitivity Analysis: Analysis is crucial for evaluating economic models as it identifies how changes in key input parameters affect outcomes.

3. Results

The cost-minimization analysis was performed to assess the financial benefits of implementing AI methods for processing negative chest X-rays in comparison to traditional manual approaches. The analysis calculated cost savings as a percentage of a radiologist's monthly salary specifically allocated to the processing of negative cases. The findings clearly demonstrate a stark contrast between the two methods in terms of efficiency and economic advantage. While the manual method yields no financial savings, as it depends entirely on the radiologist's effort and time for every case, the AI-based approach significantly reduces the workload associated with negative case processing and delivers measurable cost savings.

To illustrate this, the average monthly salary of a radiologist was estimated at 134,000 CZK. Approximately 50% of this amount, or 67,000 CZK, is allocated to the processing of normal imaging cases. Considering that 25.19% of their workload focuses on chest X-rays, and the implementation of AI results in a 62.82% reduction in workload, the monthly cost savings per radiologist are calculated at 10,602 CZK. When extrapolated over a full year, the total economic benefit per radiologist amounts to 127,228 CZK. Furthermore, with an average of 5.45 radiologists per facility, the potential monthly savings per facility reach 57,783 CZK, leading to an annual savings of 693,396 CZK per facility.

Table 3. Cost savings from AI-generated reporting for negative chest X-rays

Category	Value (CZK)
Average monthly salary of radiologist	134,000
Workload allocated to negative cases (50%)	67,000
Savings with AI (62.82%) applied for chest X-rays	10,602
Annual savings (1 radiologist)	127,228
Monthly savings per facility (5.45 radiologists)	57,783
Annual savings per facility	693,396

These results highlight the transformative potential of AI in optimizing medical imaging workflows. Beyond immediate financial benefits, the reduction in time and effort required for negative case processing also allows radiologists to focus on more complex and critical tasks, further enhancing the overall efficiency and quality of healthcare delivery. The integration of AI solutions thus represents not only a cost-effective measure but also a strategic improvement in resource utilization within radiological practices.

The sensitivity analysis of radiologist salaries was conducted using the 1st and 9th decile salary data for 2023, as provided by the Czech Statistical Office (CSO). At the 1st decile salary level of 78,670 CZK, the monthly savings per radiologist amount to 6,225 CZK, leading to an annual saving of 74,700 CZK, while for an average healthcare facility with 5.45 radiologists, the monthly savings reach 33,924 CZK, totaling 407,088 CZK annually. Conversely, at the 9th decile salary level of 189,780 CZK, the monthly savings per radiologist increase to 15,016 CZK, translating to an annual saving of 180,192 CZK, and for an average facility, the monthly savings amount to 81,836 CZK, with an annual total of 982,032 CZK. These results underscore the economic viability of AI implementation in radiology across various salary levels, demonstrating that even in lower salary scenarios, the cost-saving potential remains substantial, further supporting the financial rationale for AI adoption in radiology workflows.

If the number of radiologists per facility is adjusted to 2 instead of the average 5.45, the estimated monthly savings would be 21,205 CZK, totaling 254,456 CZK annually. Conversely, if the facility employs 10 radiologists, the potential monthly savings would increase to 106,023 CZK, leading to an annual total of 1,272,276 CZK. These calculations highlight how facility size and staffing levels significantly impact the overall financial benefits of AI-assisted solutions in radiology workflows.

4. Discussion

The results highlight the significant financial benefits that the implementation of AI methods can bring to radiology workflows, particularly in the processing of negative chest X-rays. By automating routine tasks such as evaluating negative cases, AI reduces the workload on radiologists, leading to considerable cost savings. For an individual radiologist, the calculated savings amount to 10,602 CZK per month, equating to an annual saving of 127,228 CZK. When considering the average number of 5.45 radiologists per facility, the potential monthly savings reach 57,783 CZK, resulting in annual savings of 693,396 CZK per facility.

It is important to acknowledge that the actual financial benefits achieved in any healthcare facility depend on several factors, including the proportion of time radiologists dedicate to chest X-rays, workload distribution across the team, and the associated costs of AI adoption, such as acquisition, implementation, and maintenance expenses. While the financial advantages are promising, a thorough cost-benefit analysis is necessary to fully understand the return on investment and long-term feasibility for healthcare providers.

The scalability of AI solutions becomes evident when analyzing different facility sizes. If a facility operates with 2 radiologists, the estimated monthly savings amount to 21,205 CZK, accumulating to an annual saving of 254,456 CZK. On the other hand, in larger facilities with 10 radiologists, the monthly savings increase to 106,023 CZK, with an annual total of 1,272,276 CZK. These variations demonstrate the adaptability of AI technology to different healthcare settings and its potential to significantly enhance cost-efficiency in radiology departments.

Beyond direct financial savings, AI integration offers further benefits, such as enabling radiologists to allocate more time to complex diagnostic tasks that require their expertise. This shift not only enhances the quality of healthcare services but also addresses the growing demand for radiological services amid workforce shortages. Moreover, the ability to reallocate human resources efficiently contributes to improved patient outcomes and better utilization of healthcare infrastructure.

In conclusion, the adoption of AI in radiology presents a strategic opportunity for healthcare providers to achieve substantial cost savings and operational efficiencies. However, successful implementation requires careful consideration of local conditions, including workload patterns, staffing levels, and financial resources. Facilities that effectively integrate AI into their workflows can expect not only significant economic benefits but also improvements in service quality and accessibility, making AI a valuable long-term investment in modern healthcare.

5. Conclusions

The findings of this study demonstrate that the implementation of AI methods for processing low-risk chest X-rays can lead to significant reductions in personnel costs and improved workflow efficiency within radiology departments. By automating the evaluation of negative cases, which typically constitute a substantial portion of a radiologist's workload, AI solutions enable healthcare facilities to optimize resource allocation and achieve notable financial savings.

Beyond direct financial benefits, the integration of AI in radiology presents a broader spectrum of advantages. AI not only enhances operational efficiency but also serves as a valuable support tool for radiologists, assisting in decision-making, reducing diagnostic errors, and improving overall accuracy (Abraham & Thakrar, 2004; Shin et al. 2022; King's College London, 2023). These contributions have the potential to enhance patient outcomes, streamline diagnostic processes, and alleviate the burden on healthcare professionals, particularly in the context of increasing demand for radiological services and workforce shortages.

However, it is important to acknowledge the limitations of this study. The economic evaluation focused primarily on the cost-saving potential of AI-generated reporting for negative chest X-rays, which represents only one aspect of AI's broader impact in radiology. Other potential benefits, such as improved diagnostic consistency, earlier detection of critical conditions, and enhanced workflow management, were not quantified within the scope of this analysis. Additionally, factors such as the cost of AI system implementation, training, and long-term maintenance must be carefully considered to fully assess the return on investment.

Future research should explore the comprehensive impact of AI adoption in radiology, considering not only its economic implications but also its effects on diagnostic accuracy, radiologist workload satisfaction, and overall healthcare quality. Addressing these aspects will enable healthcare providers to make well-informed decisions regarding the integration of AI into clinical practice.

In conclusion, while AI-generated reporting provides tangible cost savings and efficiency improvements, its true value lies in its multifaceted contributions to radiology. Effective implementation of AI requires a balanced approach that takes into account both financial and clinical perspectives, ensuring that it serves as a strategic tool to enhance patient care and optimize healthcare delivery.

Conflict of interest: none

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Global Trends in Board Diversity: A Bibliometric Analysis

Sára SEDLÁKOVÁ* and Jana HINKE

University of West Bohemia, Pilsen, Czech Republic; sedlaks@fek.zcu.cz; hinke@fek.zcu.cz

* Corresponding author: sedlaks@fek.zcu.cz

Abstract: This study examines global trends in board diversity using bibliometric analysis, offering an overview of this research field. Board diversity, including gender, age, ethnicity, and other demographic factors, is increasingly relevant for corporate governance, CSR, and firm performance. Data from 3,536 English-language publications in the Web of Science database were analyzed. The bibliometric analysis involved evaluating publication trends by year and country, keyword mapping using VOSviewer software, and citation analysis of the most influential articles. Results highlight a growing interest in board diversity since 2010, with gender diversity as the most frequently studied aspect, often linked to the implementation of quotas. Key topics include the effects of gender diversity on governance, CSR and ESG integration, as well as financial impacts of board composition. The research is concentrated in Anglo-Saxon countries, notably the USA and the UK. Emerging trends reveal connections between diversity and sustainability, reflecting broader societal concerns. Despite advances, areas like ethnic and age diversity remain underexplored, offering opportunities for future research. This analysis confirms the multidimensional importance of board diversity for enhancing corporate governance and performance, while also identifying gaps in the current literature that warrant further investigation.

Keywords: board diversity; corporate governance; gender diversity; bibliometric analysis

JEL Classification: G34; M14; J16

1. Introduction

Diversity in the composition of corporate boards has become a key topic in the world in recent years. This trend reflects the growing importance of inclusion and equality, not only as an ethical standard but also as a factor that can impact a company's performance. Board diversity can take various forms, including gender, age, ethnicity, professional and cultural diversity.

Legislation regarding gender quotas varies across countries but generally includes a set quota (33–50%), a timeframe (3–5 years) and penalties for non-compliance. For example, Norway introduced a 40% gender quota for women in 2003, effective from 2006 for state-owned companies and from 2008 for publicly traded companies. Similarly, Spain adopted a gender quota in 2007, requiring large companies to comply by 2015. Other countries, such as Belgium, France and Iceland, have also implemented gender quotas, while 15 other nations require gender diversity reporting based on the "comply or explain" principle. Voluntary

targets are in place in countries like Austria and Poland. In contrast, some countries, such as Japan and Mexico, have minimal public discussion on gender quotas (Terjesen et al., 2015).

In 2022, the European Parliament and the Council adopted Directive (EU) 2022/2381 on November 23, marking the culmination of a decade-long process since its initial proposal. The directive aims to promote transparency in corporate recruitment practices, targeting gender balance by June 2026. Specifically, it seeks to ensure that at least 40 % of non-executive director roles and a minimum of 33 % of all director positions are occupied by individuals from the underrepresented gender, which is predominantly women in most cases.

Erhardt et al. (2003) examine the relationship between board diversity, measured by the representation of women and minorities, and corporate financial performance. Based on data from 112 large U.S. companies, they identified a positive correlation between board diversity and financial indicators such as return on assets (ROA) and return on investment (ROI). Diverse boards contribute to improved strategic decisions, innovation, and effective oversight. These findings align with studies like Campbell and Mínguez-Vera (2008), who found that gender diversity in Spanish firms enhances decision-making and board oversight, generating economic benefits without adverse market impacts. Similarly, Adams and Ferreira (2009) observed that gender-diverse boards improve oversight and accountability in companies with weaker governance structures but may reduce value in well-governed firms due to the costs of excessive monitoring. Extending these insights, Liu et al. (2014) examined the effects of board gender diversity in China, where governance frameworks are comparatively weaker. They found a significant positive relationship between diversity and firm performance, with female executive directors exerting a stronger influence on outcomes than independent female directors, emphasizing the operational value of leadership diversity. Moreover, their findings highlight the critical mass theory, which posits that boards with three or more women have a substantially stronger positive impact on performance compared to those with fewer women. Interestingly, the study also revealed that these benefits are more pronounced in legal person-controlled firms, where profit motives dominate, rather than state-controlled firms, where political and economic priorities may dilute the focus on performance. While theoretical approaches propose various mechanisms for how diversity influences corporate performance, Firew (2024) notes that research remains inconclusive, with mixed and sometimes contradictory findings. A definitive consensus on the impact of gender diversity on firm performance has yet to be established.

In terms of age diversity, a study by Fernández-Temprano and Tejerina-Gaite (2020) highlights that several factors associated with board diversity have a significant impact. One of the most notable is age diversity, which positively influences return on assets (ROA) for both supervisory and executive directors. It appears that the attributes of younger and older directors complement each other, enabling companies to manage their assets more effectively and capitalize on these differences. In contrast, Gardiner (2024) argues that there is a lack of compelling evidence to support the idea that board member age diversity predicts firm performance. After reviewing 26 years of quantitative research, Gardiner (2024) concludes that most studies fail to find a significant association between age diversity on boards and either the financial or non-financial outcomes.

In recent years, studies have increasingly explored the link between board diversity and CSR, which is gaining importance. For instance, Cook and Glass (2018) found that even solo women on corporate boards improve CSR performance compared to all-male boards. However, boards with three or more women achieve significantly stronger outcomes in areas such as governance and community engagement, while the impact on environmental sustainability remains modest, indicating that even a single female director can play a meaningful role in this area. This is also confirmed by the study by Tapver (2019), which emphasizes the role of board diversity, including gender representation, as a key factor influencing CSR disclosures in the financial sector. The study concluded that women on boards positively contribute to CSR performance, provided these roles are integrated voluntarily and align with broader governance strategies.

Another study by Agustia et al. (2022) demonstrated that board nationality diversity positively impacts firm value. The study highlights that directors from diverse countries provide a competitive advantage, enabling companies to expand their international networks. Additionally, the presence of foreign directors contributes significantly to strategic decision-making, particularly in areas related to international strategies.

Article focuses on analyzing current trends in board diversity research through bibliometric analysis. This approach reveals not only key topics but also areas that deserve greater attention in both academic and practical contexts. A search query including terms related to board diversity was defined, and data were downloaded from the Web of Science database. The time frame was not restricted, allowing all published articles on the topic to be included in the analysis. Subsequently, a descriptive analysis was conducted, evaluating the number of publications by year and country. Key topics were visualized using VOSviewer software, enabling the identification of major research areas and their interconnections. The analysis also included the frequency of keyword occurrences and their temporal dynamics. Special attention was paid to the most cited articles on board diversity. A content analysis of these studies was performed, focusing on their main themes, methodologies used and key findings. This systematic approach provided us with a comprehensive overview of the current state of board diversity research and identified areas that require further attention.

2. Methodology

Bibliometric analysis is a tool for researchers aiming to uncover trends in research areas of journals and articles, map collaboration, and identify key topics within a specific field. This method leverages extensive datasets, often containing hundreds to thousands of entries, to analyze objective metrics such as citation counts, publication volumes, and keyword occurrences. At the same time, it combines objective analysis (e.g. performance metrics) with subjective evaluation (e.g. thematic analysis) conducted through systematic methods. As a result, bibliometric analysis can reveal accumulated knowledge and developmental nuances in established disciplines. When executed effectively, this analysis can drive the field forward by offering a comprehensive overview, identifying research gaps, and inspiring new research ideas (Donthu et al., 2021).

2.1. Defining Searching Terms

The search process in bibliometric analysis should be transparent, understandable, and easily reproducible. For this analysis, the search string from the study by Khatib et al. (2023) was used. Certain words, specifically cognitive and education, were omitted from the string as they distorted the search results. The final search string was formulated as follows: [("board* diversity" OR "corporate governance" OR "board* of director*" OR "board* composition") AND (female* OR gender OR women OR age OR ethnic* OR nationality OR demographic*)].

2.2. Search Delimiting Criteria

Data from the Web of Science database were downloaded in December 2024. An initial search was conducted, yielding 4,809 results related to diversity in corporate boards. From these results, only articles in English (4,257 results) were included. The search was further narrowed to areas such as Business Finance, Business, Management, Economics, Ethics, Social Sciences Interdisciplinary, Women's Studies, and Social Issues, resulting in 3,536 entries.

3. Results

3.1. Publications by Year

A descriptive analysis of 3,536 articles was conducted. The number of articles published each year was analyzed.

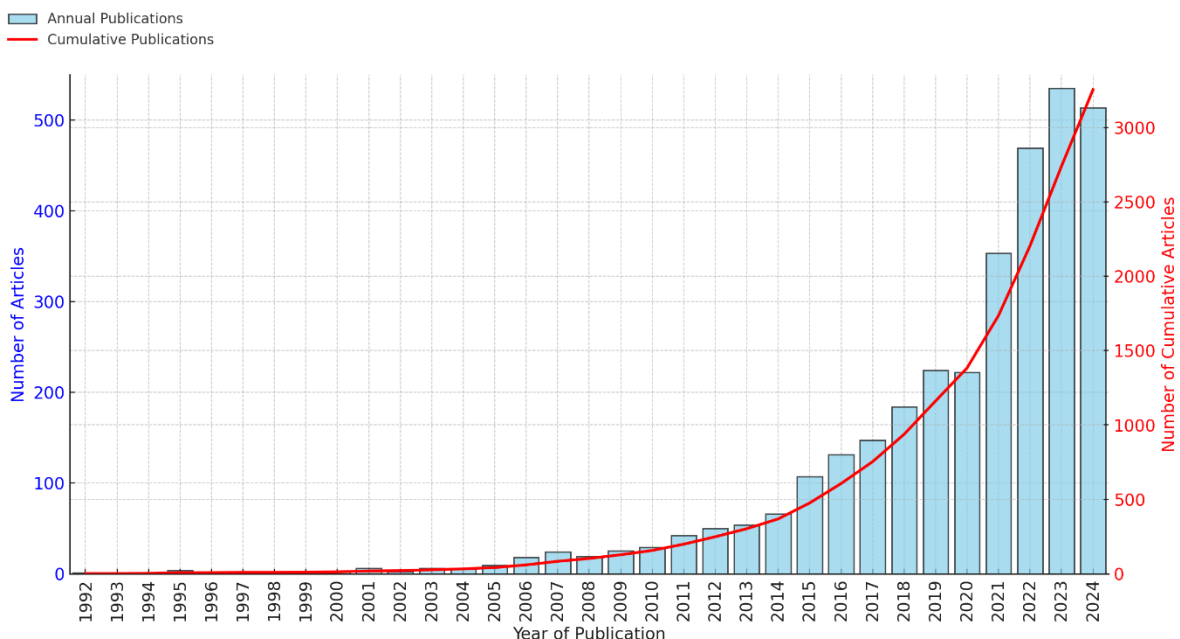


Figure 1. Cumulative and annual numbers of publications

Until 1992, only one paper on the analyzed topic had been published. Up until 2010, the number of annual publications remained very low, mostly under 20 articles per year. A slight increase was observed in 2009, with 25 publications, and since then, the number of annual

contributions has gradually grown. A more significant rise began in 2012, with 50 articles published, and this trend continued into 2013 (54 publications) and 2014 (66 publications). After this period, the growth intensified, with annual publications exceeding 200 articles each year from 2020 onward. The highest values were recorded in recent years, with 535 articles published in 2023 and 514 in 2024. Overall, the data indicate an accelerating interest in this topic, which may reflect the increasing importance of diversity and inclusion in corporate governance and research in general.

3.2. Publications by Country

A further analysis was conducted on the geographical distribution of publications on the topic of board diversity.

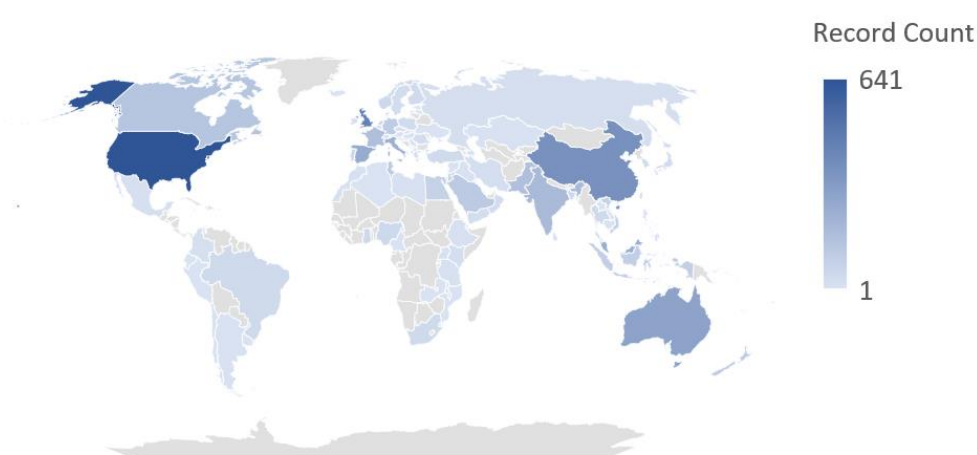


Figure 2. Publications by country

The geographical distribution of publications can be categorized into clusters based on the intensity of the blue shading on the map. Countries with the darkest blue, such as the USA (641 records, 18.13 % of the total), the United Kingdom (437 records, 12.36 %), and China (369 records, 10.44 %), represent regions with the highest publication density and dominate the field of research on board diversity. The medium blue shades indicate countries with moderate publication density, including Australia (289 records, 8.17 %) and Spain (249 records, 7.04 %), which also contribute significantly to the research. Lighter blue shades represent countries with fewer publications but a growing interest in board diversity research. These clusters underscore the dominance of Anglo-Saxon countries in this field while highlighting the increasing global significance of the topic.

3.3. Keyword Analysis

Table 1 presents the top 50 keywords ranked by the frequency of their occurrence, enabling the identification of key trends and dominant areas of focus. Board diversity is a highly relevant and multifaceted topic in contemporary research, with corporate governance emerging as the most frequently discussed theme. This emphasizes the strong link between board diversity and corporate governance, reflecting its critical role in corporate management and board responsibilities. Another significant focus area is the impact of

diversity on firm performance, as evidenced by keywords such as "firm performance" and "financial performance." These terms highlight a consistent research interest in how diversity influences efficiency and financial outcomes.

Table 1. Top 50 keywords by the frequency of their occurrence

Keyword	Occurrences	Keyword	Occurrences
Corporate governance	2,211	Disclosure	232
Firm performance	1,109	Upper echelons	218
Gender diversity	1,085	Board	214
Directors	951	Quality	207
Impact	936	Size	189
Performance	878	Sustainability	183
Women	800	Panel-data	181
Ownership	766	Corporate social responsibility	178
Governance	663	Boards	176
Diversity	506	Board characteristics	175
Gender	496	Agency	175
Management	469	Audit committee	166
Determinants	436	Risk	162
Board of directors	431	Social-responsibility	157
Financial performance	396	Corporate boards	155
Board diversity	350	Independence	146
Corporate social-responsibility	324	Empirical-evidence	139
Board composition	310	Top management	139
Firm	307	Ethnic diversity	133
Women directors	293	Leadership	133
Board gender diversity	290	Gender-differences	131
Earnings management	285	Compensation	126
Female directors	275	Agency theory	124
Ownership structure	258	CSR	122
Agency costs	232	Environmental performance	115

Gender diversity stands out as a central theme, with terms like "women", "female directors" and "board gender diversity" underscoring its importance. This suggests that achieving gender balance remains a key aspect of diversity-related studies. In addition to gender, the broader concept of diversity, encompassing elements such as ethnic, professional, and educational diversity, also garners attention. This indicates an ongoing exploration of how various forms of diversity contribute to organizational effectiveness. The analysis also highlights a strong emphasis on governance, as reflected in keywords such as "governance" and "board of directors." These terms signal a focus on board structures and governance processes, further enriched by related topics such as "board composition", "board characteristics", and "independence." This demonstrates an interest in understanding how board makeup and governance practices influence corporate decision-making.

Additional trends reveal a growing connection between diversity and environmental and social issues. Terms like "corporate social responsibility", "environmental performance", and "sustainability" suggest that diversity is increasingly linked to broader themes of sustainability and corporate social responsibility. Similarly, terms such as "leadership,"

"agency theory," and "top management" reflect a focus on how diversity affects managerial and strategic decision-making processes.

From a methodological perspective, the frequent use of terms like "empirical evidence" and "panel-data" indicates a preference for quantitative approaches, utilizing statistical analyses to examine the effects of diversity. The term "disclosure" further emphasizes the role of transparency and reporting in measuring and understanding diversity.

Overall, the analysis confirms that board diversity continues to be a vital area of inquiry, with significant attention given to its implications for firm performance and governance. The evolving linkage between diversity and themes such as sustainability and corporate social responsibility highlights the need for more inclusive and comprehensive research, particularly in underrepresented areas like ethnic diversity and cultural contexts.

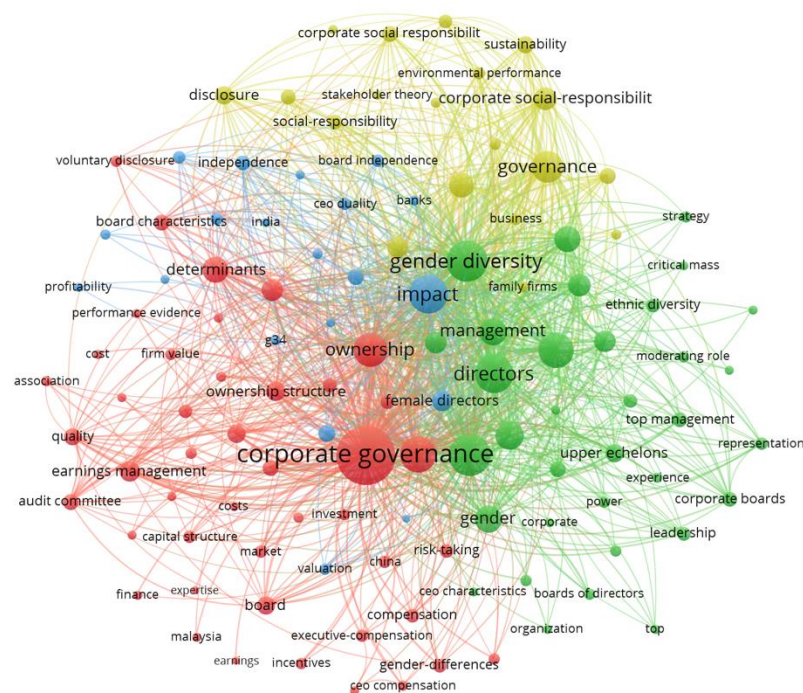


Figure 3. Cluster analysis of keywords

The analysis of the VOSviewer keyword map reveals thematic clusters in board diversity research, which are color-coded. The red cluster focuses on corporate governance, including topics such as ownership structure, earnings management, board characteristics, and agency theory. The green cluster emphasizes gender diversity, particularly the integration of women into boards and their impact on firm performance. The yellow cluster connects board diversity with sustainability and social responsibility, reflecting the growing importance of ESG (Environmental, Social, Governance) topics. The blue cluster explores links between diversity, firm performance, and financial outcomes, featuring keywords like profitability and audit committee.

Corporate governance is the central theme connecting all clusters, while gender diversity bridges governance (red cluster) and sustainability (yellow cluster). Ownership structures link traditional governance topics (red cluster) with financial performance (blue cluster). Significant keywords, such as corporate governance, gender diversity, and sustainability,

dominate, while smaller terms like ethnic diversity and representation suggest an expansion of research directions. The color-coded clusters highlight thematic connections and indicate a shift from traditional governance studies to broader societal issues, confirming the multidisciplinary nature of board diversity research.

Figure 4. Cluster analysis of keywords by year

The VOSviewer keyword map analysis highlights the evolution of board diversity research from 2019 to 2022, with keywords color-coded by their time of occurrence. Older topics (2019–2020, blue and green), such as corporate governance, ownership, and board composition, dominate established research areas, while newer topics (2021–2022, yellow), like sustainability and corporate social responsibility, indicate a shift toward environmental and social issues.

3.4. Publications by Citation Count

Table 2 presents the three most influential articles based on the number of citations, focusing on diversity in boards.

Table 2. Top 3 articles by the number of citations

Publication	Year	Authors	Citations	
			Average per year	Total
Women in the boardroom and their impact on governance and performance	2009	Adams, Renee B.; Ferreira, Daniel	168.06	2,857
Gender Diversity in the Boardroom and Firm Financial Performance	2008	Campbell, Kevin; Minguez-Vera, Antonio	65.94	1,187
The Impact of Board Diversity and Gender Composition on Corporate Social Responsibility and Firm Reputation	2010	Bear, Stephen; Rahman, Noushi; Post, Corinne	73.81	1,181

The most cited article, "Women in the Boardroom and Their Impact on Governance and Performance" (Adams & Ferreira, 2009), with 2,857 citations, highlights the crucial importance of gender diversity. All the referenced studies emphasize the key role of diversity in improving corporate performance, reputation, and social responsibility, thereby confirming its relevance across various aspects of management.

Table 3. Top 3 articles by the number of average citations per year

Publication	Year	Authors	Citations	
			Average per year	Total
Women in the boardroom and their impact on governance and performance	2009	Adams, Renee B.; Ferreira, Daniel	168.06	2,857
WOMEN ON BOARDS AND FIRM FINANCIAL PERFORMANCE: A META-ANALYSIS	2015	Post, Corinne; Byron, Kris	88.27	971
Gender diversity, board independence, environmental committee and greenhouse gas disclosure	2015	Liao, Lin; Luo, Le; Tang, Qingliang	82.55	908

Table 3 offers a different perspective on publication impact by focusing on the average number of citations per year rather than the total count. This approach helps identify more recent studies that have quickly gained recognition in the academic community. While the article by Adams and Ferreira (2009) remains the most influential with the highest average citation rate (168.06 per year), the second and third positions are occupied by newer studies from 2015.

3.5. Content Analysis

As part of further analysis, the three most-cited publications were examined. Their main topics and methodologies were briefly outlined, and their key findings were summarized. Additionally, articles with the highest average citation rate per year will be analyzed, with the first one also having the highest total number of citations.

Women in the boardroom and their impact on governance and performance

The article by Adams and Ferreira (2009) examines the impact of gender diversity on corporate boards, focusing on governance and performance outcomes. Using data from over 1,900 U.S. companies between 1996 and 2003, the study employs statistical methods, including firm-fixed effects models and instrumental variable techniques, to address endogeneity issues and analyze the effects of female board members on key governance metrics. The results reveal that women on boards have better attendance and are more likely to be assigned to monitoring-related committees, such as audit and governance committees. Boards with a higher proportion of women demonstrate stronger CEO accountability, with CEO turnover being more sensitive to stock performance. However, the study finds that the average effect of gender diversity on firm performance is mixed. While diversity improves outcomes in poorly governed firms, it may be counterproductive in well-governed firms due to excessive monitoring. The findings suggest that mandatory quotas for female directors might reduce firm value in certain contexts, emphasizing the need for a nuanced approach to board diversity policies.

Gender Diversity in the Boardroom and Firm Financial Performance

The article by Campbell and Minguez-Vera (2008) investigates the relationship between gender diversity on corporate boards and firm financial performance, using data from Spanish non-financial firms listed on the Madrid stock exchange between 1995 and 2000. The study employs panel data methodology and uses Tobin's Q as a measure of firm value, along with various diversity indices, including the Blau and Shannon indices, to assess gender diversity. The results demonstrate that while the mere presence of women on boards does not significantly impact firm value, greater gender diversity positively influences firm performance. This finding suggests that achieving a balance between male and female board members is more important than simply increasing the number of women on boards. The study also highlights the absence of a significant effect of firm value on gender diversity, indicating a one-way causal relationship where gender diversity drives firm performance. This research contributes to the growing body of literature on board diversity by providing evidence from Spain, a civil law country with unique corporate governance characteristics, and supports the notion that gender diversity can enhance shareholder value without detriment to financial performance.

The Impact of Board Diversity and Gender Composition on Corporate Social Responsibility and Firm Reputation

The article by Bear et al. (2010) examines how diversity in board resources and gender composition influences corporate social responsibility (CSR) ratings and corporate reputation. The study utilizes Ordinary Least Squares regression analysis on lagged data from a sample of healthcare companies to explore these relationships. The findings reveal that the presence of women on boards positively impacts CSR ratings and that these ratings, in turn, enhance corporate reputation. However, the study found no significant relationship between the diversity of board resources (e.g. professional backgrounds) and CSR ratings. The analysis also demonstrates that CSR mediates the relationship between the number of women on the board and corporate reputation, highlighting the role of gender diversity in improving stakeholder perceptions and firm reputation. This study emphasizes the importance of board diversity, particularly gender diversity, as a mechanism for fostering CSR and building a positive corporate reputation. It contributes to the literature by exploring CSR's mediating role and providing practical insights into how diversity affects corporate outcomes in highly scrutinized industries.

WOMEN ON BOARDS AND FIRM FINANCIAL PERFORMANCE: A META-ANALYSIS

The article by Post and Byron (2015) analyzes the impact of female board representation on firm financial performance through a meta-analysis of 140 studies from 35 countries. The findings show that women on boards enhance accounting performance, especially in countries with strong shareholder protections. The effect on market performance varies—positive in gender-equal countries but negative where equality is lower, likely due to investor bias. The study confirms that female board members improve oversight and decision-making, but the impact of gender diversity depends on context, and mandatory quotas do not always increase firm value.

Gender diversity, board independence, environmental committee and greenhouse gas disclosure

The article by Liao et al. (2015) examines the impact of board composition on the voluntary disclosure of greenhouse gas (GHG) emissions through the Carbon Disclosure Project. A sample of 329 of the largest UK companies is analyzed, showing that a higher proportion of women, independent board members, and the presence of an environmental committee are associated with greater transparency in climate strategies. However, if the committee is not sufficiently large, independent, or active, its influence appears to be limited. The study is based on stakeholder theory and emphasizes that effective corporate governance is crucial for promoting environmental responsibility.

4. Discussion

This study provides a comprehensive view of global trends in board diversity through bibliometric analysis, highlighting the growing significance of this topic in both academic and practical contexts. The findings emphasize that gender diversity is the most extensively studied aspect, aligning with key studies such as the work by Adams and Ferreira (2009), who demonstrated its benefits for corporate governance, particularly in less effectively managed firms. Similarly, Campbell and Minguez-Vera (2008) stressed that balanced representation of men and women on boards positively affects firm value. Moreover, the critical mass theory suggests that boards with three or more women achieve significantly better governance and performance outcomes (Liu et al., 2014). These studies collectively support the idea that gender diversity is a cornerstone of board diversity research, consistent with the keyword analysis in this study.

In addition to gender, the connection between board diversity and corporate social responsibility (CSR) is gaining prominence. Bear et al. (2010) showed that women on boards improve CSR ratings and corporate reputation, while Tapver (2019) demonstrated that voluntary gender diversity in the financial sector significantly enhances the quality of CSR reporting. These insights, supported by keyword trends in this study, underscore the growing integration of environmental, social, and governance (ESG) themes into the discourse on board diversity.

Emerging dimensions of board diversity, such as age and ethnic diversity, also have the potential to enrich corporate governance and performance. Fernández-Temprano and Tejerina-Gaite (2020) identified a positive impact of age diversity on return on assets (ROA), attributing this to the complementary attributes of younger and older board members. On the other hand, Gardiner (2024) highlighted inconsistent evidence linking age diversity to firm performance, indicating the need for further exploration. Ethnic and nationality diversity, as studied by Agustia et al. (2022), demonstrated a positive relationship with firm value, suggesting that diverse perspectives contribute to strategic decision-making and international competitiveness.

Despite these advances, bibliometric analysis identifies overlooked areas in board diversity research. Ethnic and cultural diversity, as well as intersectional approaches combining multiple dimensions of diversity, remain relatively underexplored. Addressing these gaps could provide a more comprehensive understanding of how diversity impacts corporate outcomes.

The findings confirm that board diversity is a multidimensional concept that extends beyond gender, encompassing broader demographic and professional characteristics. Future studies should delve deeper into these less-explored areas to fully realize the potential of diversity in improving corporate governance and achieving sustainable business growth.

5. Conclusions

Global trends in board diversity show that it is a topic of growing interest, particularly since 2010. The most significant areas of research include gender diversity, its impact on corporate performance and corporate social responsibility (CSR), and its connection to ESG (Environmental, Social, Governance) concepts. The majority of publications originate from Anglo-Saxon countries, such as the USA and the United Kingdom.

Gender diversity is a key aspect of current studies. Research indicates that the presence of women on corporate boards positively influences corporate governance, CSR, and corporate reputation. While gender diversity receives substantial attention, other dimensions, such as ethnic, age, or cultural diversity, remain relatively underexplored. These areas offer opportunities for further research and a deeper understanding of the role of diversity in corporate governance.

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Conflict of interest: none

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Energy Communities in the Energy Transition: An Analysis of Thiers Role in the Implementation of Local Climate Strategies and Economic Benefits in Poland and the Czech Republic

Sławomir STEC^{1*} and Maciej MROZOWSKI²

¹ Rzeszow University of Technology, Rzeszów, Poland; s.stec@prz.edu.pl

² Ignacy Łukasiewicz Institute for Energy Policy, Jasionka, Poland; mmrozowski@instytutpe.pl

* Corresponding author: s.stec@prz.edu.pl

Abstract: The energy transition is one of the key challenges of the modern world, with the aim of counteracting climate change, reducing greenhouse gas emissions and increasing energy security. The article analyzes the role of energy communities in Poland and the Czech Republic as an important element of local climate strategies and their impact on the economics of households and enterprises. Legal regulations, organizational models and economic functioning of energy communities are discussed, indicating their potential for decentralization of the energy system and the development of renewable energy sources. The economic analysis confirms that belonging to energy communities allows for significant savings – in Poland, the cost of electricity for households can be reduced by up to 40%, and for small enterprises by nearly 50%. In the Czech Republic, these savings amount to an average of 25-30%. In addition, energy communities contribute to increasing energy independence, reducing transmission losses and improving the efficiency of energy management. Despite its numerous benefits, the development of energy communities faces significant legal, financial and administrative barriers. The article points to the need to simplify administrative procedures, stabilize the support system and facilitate access to funds for energy communities. Their development can be a key element of future climate and energy policy, enabling the implementation of sustainable development goals and strengthening the energy security of regions.

Keywords: energy communities; energy cooperatives; energy transition; climate strategies; Poland; Czech Republic

JEL Classification: Q42; Q48; R11

1. Introduction

The energy transition is one of the most important challenges of the 21st century. In the face of climate change and the need to ensure energy security, the importance of local climate strategies is growing. These strategies play a key role in meeting global greenhouse gas emission reduction targets by increasing the share of renewable energy sources (RES) and promoting sustainable development at the local level. Thanks to their reach and adaptability

to the specifics of local communities, they allow for the effective implementation of solutions supporting the energy transition (Bulkeley, 2013).

One of the most interesting solutions supporting the implementation of local climate strategies are energy communities. Defined as initiatives in which citizens, local governments and other entities jointly produce, consume and manage energy, energy communities aim to decentralise the energy system, develop renewable energy sources and increase environmental awareness (REScoop.eu, 2020). In Europe, their development is particularly noticeable in countries such as Germany, Scandinavia and the United Kingdom, where numerous organizational models operate, e.g. energy cooperatives, local civic power plants and public-private partnerships.

Energy cooperatives, whose development began in the Nordic countries, are one of the most popular forms of energy communities. In Germany, these communities have thousands of members, jointly investing in local renewable energy sources, which allows for increased energy independence and reduced transmission losses. In the UK, on the other hand, models of cooperation with the private and public sectors are being implemented, enabling effective energy management at the level of municipalities and regions (European Commission, 2019).

The aim of the article is to examine the impact of energy communities on the implementation of local climate strategies in Poland and the Czech Republic, including their potential in the context of energy decentralization, development of renewable energy sources and public awareness. In addition, the analysis includes an assessment of the economic benefits of belonging to energy communities, based on a comparison of two countries.

The hypothesis assumes that energy communities support the implementation of local climate strategies in Poland and the Czech Republic through the decentralization of energy production, the development of renewable energy sources and increasing public awareness. The result of these activities is a reduction in CO₂ emissions, improved energy security and measurable economic benefits for community members.

2. Methodology

The article uses the method of comparative analysis, taking into account the legal, organizational and economic aspects of the functioning of energy communities in Poland and the Czech Republic. The analysis included:

- Review of legal documentation – analysis of the RED II regulations and national legal acts,
- Economic research – simulation of the costs of annual energy consumption for households and small enterprises,
- Analysis of case studies – comparison of selected examples of energy communities in both countries,
- Statistical methods – development of tables illustrating savings resulting from belonging to energy communities.

In order to indicate the economic benefits of belonging to energy cooperatives, a simulation of annual energy costs for households and small enterprises located in the Czech

Republic and Poland was carried out. Similar energy consumption for households was assumed at the level of 3,000 kWh per year and 10,000 kWh for small enterprises. Costs are in dollars, taking into account the exchange rate as of January 28, 2025 (\$1 = CZK 24.04; \$1 = PLN 4.03), which allows for an economic comparison in countries with different currencies (Google exchange rates USD/CZK, Google exchange rates PLN/CZK). The maximum prices set by the governments of both countries for households and small businesses in accordance with the applicable legislation have been taken into account. The calculation was made for both clean energy and energy, including distribution costs, taxes, and other charges. In the case of energy cooperatives, the cost of membership fees of \$208 per year in the Czech Republic and \$124 in Poland was added.

Energy prices for customers from the Czech Republic were adopted on the basis of Price Decision No. 5/2023 and 6/2023 of the Energy Regulatory Office and a price calculator (Energetický Regulační Úřad, 2023a; 2023b; TZB-info, 2025). On the other hand, the prices for Polish energy consumers were adopted on the basis of the Act of 27 November 2024 amending the Act on Emergency Measures to Limit Electricity Prices and Support for Certain Consumers in 2023–2024 (Dz.U. z 2024 r. poz. 1361, 1847, 1881) and the RENALDO calculator for calculating energy prices for energy cooperatives (RENALDO, 2023).

In addition, the article has been supplemented with a detailed case study, presenting an example of the functioning of energy cooperatives in the Czech Republic and Poland, taking into account their organizational structure, management mechanisms and economic benefits.

3. Literature review

3.1. *Theoretical Foundations of Energy Communities*

The literature on the subject indicates that energy communities increase local independence, reduce transmission losses and support sustainable development (Bulkeley, 2013; European Commission, 2019). The EU promotes these initiatives, m.in. through RED II (Directive 2018/2001/EU; Regulation 2019/943/EU), but their development faces administrative, financial and organisational barriers (IRENA, 2020). In the Nordic countries, joint initiatives of local governments and citizens support renewable energy sources, facilitating the development of models of energy management and sharing economic benefits (Magnani & Osti, 2016; Brummer, 2018).

Energy communities in Poland and the Czech Republic differ in terms of legal regulations and approaches to energy organization and management. They are an important element of the modern energy transition, offering a new approach to energy production and consumption. In Poland, energy communities have been formally defined under the Renewable Energy Sources Act of 2015, which defines them as local initiatives aimed at joint management of energy generated from RES by citizens, enterprises and local government units (Act of 20 February 2015).

In Poland, energy communities are defined in the RES Act of 2015 as local initiatives managing energy by citizens, enterprises and local government units (Act of 20 February

2015). Energy cooperatives can generate electricity, heat or biogas, but they cannot sell it – they can only give the surplus back to the grid under certain rules (Medoń, 2023). Their activities are limited to one distribution operator or three neighbouring municipalities, and the minimum number of members is 10 natural persons or 3 legal entities. The technical conditions specify capacity limits – 10 MW for electricity, 30 MW for heat and 40 million m³ of biogas. By the end of 2025, the required self-consumption has been reduced from 70% to 40%, and the registration of cooperatives is carried out through the National Support Centre for Agriculture (Banaszuk et al.).

In the Czech Republic, similar regulations were introduced in 2023, defining energy communities as non-profit organizations promoting renewable energy sources and local energy supply (Act No. 458/2000 Coll.). The new act allows energy to be shared in the public grid and billed every 15 minutes. Two forms of communities have been introduced: energy (electricity) and renewable resources (heat and other sources), and members can be individuals, SMEs and local government units. A static allocation key is in place until 2026, and then a dynamic billing system is planned.

In addition, the simplified "active customers" model allows owners of small installations to share surplus energy with up to 10 collection points without creating a community. The key limitations are, m.in, the lack of full energy self-sufficiency and the possibility of participating in only one sharing group (Ander, 2023). The cooperative must meet the requirements for a minimum number of members and capital.

Members of energy cooperatives can reduce energy costs by gaining more control over its use. Economies of scale reduce investment and operational costs, e.g. through joint purchasing of technology and sharing maintenance costs. Cooperatives can take advantage of tax breaks, subsidies, and preferential loans, making them an attractive form of energy management (Kurtyka, 2022). However, a responsible approach that takes into account legal and financial aspects is crucial (Law No. 458/2000).

In terms of legal regulations, Poland supports energy communities through feed-in tariffs and subsidies, while the Czech Republic emphasizes the simplification of administrative procedures. Both countries are implementing the RED II directive, but the priorities are different.

The functioning of energy communities depends on technology, organizational structures, and business models. Photovoltaic installations, wind turbines or energy storage enable local production and distribution (IRENA, 2020). Organizationally, these can be cooperatives, associations or municipal companies, and business models are often based on joint investments and the sale of surplus energy (REScoop.eu, 2020).

3.2. Analysis of Economic Models of Functioning of Energy Communities

The economic models of energy communities are based on generating revenues, optimizing costs and financing investments. The main sources of income are the sale of energy to the grid and distribution among members at preferential rates. Many communities use support mechanisms such as feed-in tariffs or auction systems (European Commission, 2019).

Cost optimization is a key element of the efficiency of energy communities. Joint investment in infrastructure, such as photovoltaic installations or energy storage, allows you to reduce unit costs and increase the profitability of the project. In addition, communities often use technological solutions, such as energy management systems, that allow energy consumption to be monitored and optimized (IRENA, 2020).

The financing of the investment is based on own funds, subsidies and preferential loans. EU funds, such as the European Regional Development Fund, support these projects, especially in rural regions. Crowdfunding and public-private partnerships are also playing an increasingly important role, involving more entities and strengthening social acceptance (REScoop.eu, 2020).

3.3. Analysis of Economic Models of Functioning of Energy Communities

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Cost optimization is key to the effectiveness of these initiatives. Joint investments in photovoltaics or energy storage reduce unit costs and improve profitability. In addition, communities are implementing smart energy management systems to monitor consumption and minimize waste (IRENA, 2020).

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Energy cooperatives bring measurable financial benefits. In Poland, members benefit from cheaper energy thanks to local renewable energy resources, increasing their energy security. Surplus energy is settled in a discount system, where they receive 0.6 units for each unit returned to the grid. This allows you to balance energy without additional fees for commercial balancing. Members are also exempt from distribution, RES, cogeneration, capacity fees and the obligation to present certificates of origin. Energy is not subject to excise duty if the capacity of the installation does not exceed 1 MW (Banaszuk, et al).

Cooperatives also support the circular economy, e.g. by using biogas from agricultural waste, which provides energy and waste management. Thanks to the economies of scale, they can also reduce electricity costs through discounts provided for in the RES Act.

In the Czech Republic, energy communities are increasing independence from fossil fuels and reducing energy costs. They enable local production and consumption, eliminating indirect fees. Members share the costs of the installation and can obtain funding for technical documentation, energy storage and optimization of energy consumption. Thanks to these solutions, people with lower incomes gain access to cheaper energy, which reduces the risk

of energy poverty. Joint management of production and distribution allows for optimization of consumption and minimization of losses (Ministerstvo Životního Prostředí, 2023).

3.4. Local Climate Strategy and Energy Cooperatives

Energy cooperatives play an important role in local climate strategies, acting as a bridge between local governments and the community. Through the decentralization of energy production and the development of renewable energy sources, they contribute to the reduction of CO₂ emissions and the improvement of air quality (European Environment Agency, 2020). Their effective integration into municipal policies requires community involvement in the decision-making process, the organisation of consultations, and administrative and financial support.

Examples from Poland show that actively involving communities in climate strategies increases energy efficiency and the share of RES (KAPE, 2022). In the Czech Republic, energy communities reduced CO₂ emissions by 15% in municipalities implementing local RES production (International Energy Agency, 2021).

Energy communities support economic development by creating jobs and increasing the income of municipalities. Investments in photovoltaic farms or biogas plants generate employment at the construction and operation stage (IRENA, 2020). Local government units benefit from taxes and energy sales (European Environment Agency, 2020).

Supporting local companies is another aspect of their business – the use of local suppliers and service providers is conducive to the development of the regional economy. In addition, access to cheaper, green energy facilitates the activities of SMEs, which can benefit from preferential rates offered by energy communities (REScoop.eu, 2020).

3.5. Barriers to the Functioning of Local Communities

Energy communities play a key role in the energy transition, but their development faces numerous legal, financial and administrative barriers in both Poland and the Czech Republic. In Poland, the main legal obstacle is the complex and ambiguous regulatory system for energy communities. The lack of consistent definitions and precise rules makes it difficult to create and operate such initiatives. In addition, permitting procedures are time-consuming and complex, which discourages potential participants (Ministerstwo Klimatu i Środowiska, 2024).

In the Czech Republic, legislative instability is a problem. An example is the planned retroactive reduction in subsidies for photovoltaic installations in 2024, which has sparked threats of lawsuits from investors and may discourage future investments in renewable energy sources (Hancock, Minder, 2024). Financing energy communities in Poland is difficult due to limited access to funds and the lack of dedicated support programs. In addition, the high initial costs of investing in renewable energy sources are a significant barrier for local communities (Marzec, 2021).

In the Czech Republic, in addition to the above-mentioned changes in the subsidy system, limited access to finance for small and medium-sized enterprises and local communities is also a problem, which hampers the development of small-scale energy projects.

In both countries, the administrative procedures involved in the creation and management of energy communities are complex and time-consuming. In Poland, there is a lack of uniform guidelines and procedures, which leads to uncertainty and delays in the implementation of projects (Ministerstwo Klimatu i Środowiska, 2024).

In the Czech Republic, despite the growing interest in the subject of civic energy, there is a lack of coordinated action at the administrative level, which makes it difficult to implement local energy initiatives (Skórka, 2024).

Overcoming these barriers requires coordinated legislative, financial and administrative actions that will enable the development of energy communities and contribute to an effective energy transition in both countries.

4. Results

In order to indicate the economic benefits of belonging to energy cooperatives, simulations of annual energy costs for households and small enterprises located in the Czech Republic and Poland were carried out.

Simulations of energy costs carried out for households and small enterprises in the Czech Republic and Poland allow to see significant differences resulting from membership in energy cooperatives (Table 1). The analysis indicates that membership in such organizations can significantly reduce energy costs, and the scale of savings varies depending on the country and type of recipient.

In the Czech Republic, households using 3,000 kWh per year pay USD 813 for electricity, including distribution costs, taxes and other fees, if they are not members of an energy cooperative. Membership in a co-op reduces that cost to USD 606, a saving of USD 207, or 25.5%.

Table 1. Simulation of the costs of annual electricity consumption for a household in the Czech Republic depending on the membership in an energy cooperative

Specification	Annual consumption (kWh)	A household without an energy cooperative		A household that is a member of an energy cooperative	
		Price 1 kWh (USD)	Energy price per year (USD)	Price 1 kWh (USD)	Energy price per year (USD)
Energy cost	3,000	0.250*	750.00	0.187	561.00
The cost of energy including distribution costs, taxes, and other charges	3,000	0.271*	813.00	0.202	606.00

* Cost of energy including the maximum price for households

Similar trends can be observed in Poland, where a household without membership in an energy cooperative incurs annual costs of USD 819, while membership allows to reduce expenses to USD 519 (Table 2). This represents an even greater saving of USD 300, which corresponds to a reduction of 36.6%. It is clear that in the case of households, membership in an energy cooperative is more profitable in Poland than in the Czech Republic.

Table 2. Simulation of the costs of annual electricity consumption for a household in Poland depending on the membership in an energy cooperative

Specification	Annual consumption (kWh)	A household without an energy cooperative		A household that is a member of an energy cooperative	
		Price 1 kWh (USD)	Energy price per year (USD)	Price 1 kWh (USD)	Energy price per year (USD)
Energy cost	3,000	0.154*	432.00	0.099	297.00
The cost of energy including distribution costs, taxes, and other charges	3,000	0.273*	819.00	0.173	519.00

* Cost of energy including the maximum price for households

The situation is different in the case of small enterprises. In the Czech Republic, the annual electricity costs for companies consuming 10,000 kWh are USD 2,910, both for companies that are members of the cooperative and for those that do not (Table 3). The only difference is in the cost of energy alone (excluding additional fees), which is USD 630 lower for co-op members, a saving of 25.2%.

Table 3. Simulation of the costs of annual electricity consumption for a small enterprise in the Czech Republic depending on the membership of an energy cooperative

Specification	Annual consumption (kWh)	A household without an energy cooperative		A household that is a member of an energy cooperative	
		Price 1 kWh (USD)	Energy price per year (USD)	Price 1 kWh (USD)	Energy price per year (USD)
Energy cost	10,000	0.250*	2,500.00	0.187	561.00
The cost of energy including distribution costs, taxes, and other charges	10,000	0.291*	2,910.00	0.291	2 910.00

* Energy cost including maximum price for small businesses

In Poland, however, savings for enterprises are much more visible and also include full costs (Table 4).

Table 4. Simulation of the costs of annual electricity consumption for a small enterprise in Poland depending on the membership in an energy cooperative (own elaboration)

Specification	Annual consumption (kWh)	A household without an energy cooperative		A household that is a member of an energy cooperative	
		Price 1 kWh (USD)	Energy price per year (USD)	Price 1 kWh (USD)	Energy price per year (USD)
Energy cost	10,000	0.240*	2,400.00	0.112	1,120.00
The cost of energy including distribution costs, taxes, and other charges	10,000	0.360*	3,600.00	0.186	1,861.00

* Energy cost including maximum price for small and medium-sized enterprises

A non-member enterprise incurs annual expenses of USD 3,600, while for membership these costs drop to USD 1,861. This represents a saving of USD 1,739, a reduction of 48.3%.

The presented data show that Poland offers greater economic benefits from membership in energy cooperatives for both households and small enterprises. While in the Czech Republic, membership of a cooperative only brings noticeable savings for households and clean energy in enterprises, in Poland these benefits also extend to the full costs of enterprises, which makes cooperatives more attractive. This analysis indicates that energy cooperatives can significantly support the implementation of local climate strategies, reducing energy costs and increasing the share of renewable energy sources in the energy mix.

5. Discussion

The analysis of energy communities in Poland and the Czech Republic indicates that they are an important element of the energy transition, contributing to the implementation of local climate strategies and offering economic benefits to households and businesses. In both countries, the development of energy communities is supported by legal regulations, but differences in legislative and organizational approaches lead to different models of functioning. In Poland, more emphasis is placed on subsidies and regulations facilitating the functioning of energy cooperatives, while in the Czech Republic, community development is more focused on simplifying administrative procedures and ensuring freedom of action on the energy market.

In terms of economic benefits, membership in energy communities translates into significant savings in both countries. An analysis of energy costs showed that in Poland, membership in an energy cooperative allows to reduce annual electricity costs for households by more than 35%, while in the Czech Republic, the savings are about 25%. In the case of small businesses, the greatest benefits are seen in Poland, where members of energy communities can reduce energy expenses by almost half, which is an important factor supporting the competitiveness of local business.

In the context of the energy transition, energy communities also play a key role in increasing the share of renewables in the local energy mix. Energy communities contribute to the independence of local communities from central energy suppliers, while increasing the energy stability of the region. In addition, the integration of energy communities into local climate strategies allows for more effective achievement of goals related to the reduction of CO₂ emissions and the improvement of air quality.

Despite its many benefits, the development of energy communities also faces significant barriers. In Poland, the problem remains a complicated regulatory system, which hinders the rapid implementation of energy initiatives, as well as the lack of unified administrative procedures. In the Czech Republic, on the other hand, legislative instability is a significant limitation, as exemplified by the planned changes in subsidies for photovoltaic installations, which could discourage investors from further developing energy projects. In both countries, the availability of financing is also crucial – although there are support programs, many initiatives still struggle with high initial investment costs and limited access to preferential loans and grants.

The development of energy communities therefore requires action on several levels. It is necessary to simplify legal procedures, ensure stable financial conditions and increase institutional support for local initiatives. In the long term, energy communities can become one of the pillars of climate policy in both Poland and the Czech Republic, contributing to the construction of a more decentralized and sustainable energy system.

6. Conclusions

The article aimed to investigate how energy communities support the implementation of local climate strategies and what economic benefits result from belonging to them in Poland and the Czech Republic. The aim of the study also includes a comparison of the differences between these countries in the context of legal regulations, organizational models and the economic profitability of the functioning of energy cooperatives. The hypothesis was that energy communities contribute to the decentralization of energy, the development of renewable energy sources (RES) and the increase of public awareness, leading to a reduction in CO₂ emissions, improved energy security and economic benefits.

Energy communities are playing an increasingly important role in the energy transition, contributing to local climate strategies and offering economic benefits to their members. A comparative analysis of Polish and Czech countries indicates that despite differences in legal and organizational systems, these initiatives can significantly affect local energy security, energy price stability and the development of renewable energy sources.

One of the key findings of the research is that energy communities allow for significant financial savings for both households and small businesses. Membership in energy cooperatives in Poland makes it possible to reduce energy costs by up to 40%, while in the Czech Republic these savings amount to an average of 25-30%. In the case of small businesses, the benefits are even greater, which can be an important factor supporting the development of the local economy.

From a climate policy perspective, energy communities contribute to reducing CO₂ emissions and increasing the share of renewable energy sources in national energy mixes. By decentralising energy production, it is possible to reduce transmission losses and become independent of conventional energy suppliers, which increases the energy security of regions. The examples of the cooperatives analysed show that local initiatives can effectively integrate with climate plans, supporting the implementation of EU energy policy objectives.

Despite its many advantages, the development of energy communities faces legal, financial and administrative barriers. In Poland, the key obstacle is the lack of uniform regulations and the complicated process of registering cooperatives, which requires simplification. In the Czech Republic, legislative instability and the risk of changes in the support system for renewable energy sources remain a problem, which may limit long-term investments. Access to finance remains a significant challenge in both countries, especially for smaller communities, which often have limited opportunities to raise capital for infrastructure development.

Further legislative and organisational efforts are needed to fully exploit the potential of energy communities. Administrative procedures should be simplified, the stability of the support system should be ensured and access to funds for the development of energy initiatives should be facilitated. Strengthening cooperation between local governments, entrepreneurs and residents can contribute to the dynamic development of energy communities, which will become not only an element of the energy transition, but also a tool supporting local economic and social development.

In the long term, energy communities can become one of the cornerstones of the future energy system, combining both ecological and economic aspects. However, their further development requires a comprehensive approach that takes into account both the needs of local communities and the challenges of the energy transition at the national and European level.

Conflict of interest: none

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Transfer Pricing as a Tool of Global Tax Policy – Temporal and Geographical Analysis

Lucie ZIEBOVÁ* and Jana HINKE

University of West Bohemia, Pilsen, Czech Republic; silhaval@fek.zcu.cz; hinke@fek.zcu.cz

* Corresponding author: silhaval@fek.zcu.cz

Abstract: Transfer pricing, which plays a key role in international tax policy, represents one of the most extensively discussed topics in academic literature. The aim of this article is to characterize the development of scientific interest in transfer pricing, specifically to identify the main areas of focus during the period from 1975 to 2023. This goal is addressed through two research questions: first, what are the trends in the timeline of scientific publications and their connection to key regulatory initiatives, and second, what is the geographical distribution of scientific publications, identifying the countries that contribute the most to this discussion. The timeline analysis revealed that interest in transfer pricing significantly increased during periods associated with important regulatory changes, such as the publication of the OECD Transfer Pricing Guidelines in 1992, the implementation of the BEPS Action Plan since 2013, and the agreement on a global minimum tax in 2021. Geographical analysis showed the dominance of the United States, China, and several European countries, reflecting their economic and academic strength. The findings also highlight the growing role of emerging markets in academic research on transfer pricing.

Keywords: transfer price; international tax policy; global economy; OECD

JEL Classification: H25; F23; H26

1. Introduction

Transfer pricing is a key tool in international tax policy, addressing transactions between related entities, such as subsidiaries of multinational corporations. Its proper implementation affects not only taxation in individual states but also the allocation of tax revenues among jurisdictions. Consequently, transfer pricing has become a subject of regulation, with international organizations developing frameworks to ensure that transactions between related entities align with conditions that would be agreed upon between independent parties.

Among the pioneers addressing transfer pricing issues were international organizations and institutions such as the League of Nations, which in 1933 issued the Draft Double Taxation Convention. This document was the first to formulate the concept of fair allocation of tax rights based on economic presence (Lang et al., 2016). In subsequent decades, the issue of transfer pricing was extensively developed, particularly through the efforts of the Organisation for Economic Co-operation and Development (OECD). The OECD published its first recommendations on transfer pricing in 1979 as the Transfer Pricing Guidelines for Multinational Enterprises and Tax Administrations. These guidelines, regularly updated, laid the foundation

for standardizing the arm's length principle (OECD, 1979). This principle requires that transactions between related entities be valued as if conducted between independent parties.

Academic interest in the issue of transfer pricing from the 1970s to the 2020s highlights the evolution of theoretical approaches and practical challenges associated with its application in multinational corporations. In the 1970s, research focused on the theoretical optimization of transfer pricing and its practical use. Merville and Petty (1978) examined the setting of transfer prices in multinational corporations, emphasizing their role in tax optimization, risk management, and maintaining division autonomy. They pointed out that no universal method could simultaneously satisfy all corporate objectives and recommended mathematical models, such as linear programming, to balance these goals. Kanodia (1979) further developed this issue by addressing uncertainty and risk-sharing, proposing transfer pricing systems that consider different risk approaches between divisions and the headquarters. He demonstrated that proper coordination could enhance resource allocation efficiency but also highlighted the challenges in motivating managers, as incentives often fail to lead to optimal outcomes.

At the same time, Lall (1979) pointed out issues related to the control of transfer pricing in developing countries. He explained that manipulation of transfer prices is the most severe problem in industries with high technological specificity, such as the pharmaceutical sector, where comparable market prices are absent. Additionally, developing countries often lack the capacity for effective regulation, leading to further issues. Lall suggested focusing on high-risk industries and promoting international cooperation as a tool to improve transparency and oversight.

In the 1980s, academic interest shifted to the impacts of regulatory constraints and their influence on decision-making in multinational corporations. Halperin and Srinidhi (1987) examined U.S. tax regulations, specifically the "resale price" and "cost-plus" methods, demonstrating that differences in tax rates between the U.S. and foreign jurisdictions led to inefficient resource allocation and distorted corporate decisions. Companies faced challenges in aligning rules across jurisdictions, resulting in suboptimal decisions. Samuelson (1982) explored the strategic adaptation of firms to "arm's length" rules, which set limits on transfer pricing. He highlighted how companies manipulated production and sales to achieve more favorable transfer pricing, significantly influencing their economic behavior and strategy.

A broader perspective on the issue was provided by Spicer (1988), who linked transfer pricing with corporate strategy and intra-firm transactions. Spicer proposed a theory of transfer pricing, demonstrating that these prices are not just tools for tax optimization but have a fundamental impact on the broader functioning of organizations and their long-term efficiency. This approach expanded the understanding of transfer pricing, offering a new perspective on its role in organizational structure and corporate performance.

In the 1990s, transfer pricing became a key tool for coordination and decision-making in decentralized organizations. Luft and Libby (1997) highlighted fairness factors and profit comparisons between divisions that managers consider when setting transfer prices. These aspects can prolong negotiations and lead to suboptimal outcomes. Vaysman (1998) expanded research into the dynamics of transfer pricing negotiations, demonstrating that compensation systems and structured negotiation processes can align managers' goals with organizational

objectives, thereby optimizing profits and minimizing central management interventions. Chan and Chow (1997) focused on the international level, examining tax audits of transfer pricing in China. They found that Chinese authorities target companies with low profitability or long-term losses, favoring the comparable profits method, reflecting a broader regulatory approach centered on profitability.

In the first decade of the 21st century, transfer pricing gained academic attention primarily in relation to tax optimization and managerial incentives. Mehafdi (2000) focused on implementing the arm's length principle in transfer pricing, which requires that prices between related companies be set as if the transactions occurred between independent entities. Hyde and Choe (2005) concentrated their research on the dual role of transfer pricing, both in tax optimization and managerial performance evaluation. During this period, studies began to explore separate transfer prices for tax and incentive purposes, driven by stricter international tax regulations (Fjell & Foros, 2008).

Subsequent research in the 2010s focused on risks associated with transfer pricing and the profitability of multinational firms. Jost et. al (2014) demonstrated that awareness of these risks varies depending on a company's characteristics, industry, and country, influencing their approach to tax audits and optimization. Research by Merle et. al (2019) revealed how multinational firms use transfer pricing to shift profits to tax havens, directly impacting the tax revenues of individual countries. This research confirms that companies face specific risks related to compliance with tax rules, particularly when utilizing tax havens and adhering to the arm's length principle.

In recent years, particularly in the 2020s, there has been a growing interest in the debate between the arm's length principle and the profit allocation method. Studies suggest that while ALP requires extensive documentation and analysis of functions, risks, and assets, the profit allocation method offers a simpler approach to distributing profits across jurisdictions. The Base Erosion and Profit Shifting (BEPS) project has sparked broader discussions about the efficiency and complexity of these methods in international tax planning (Akhand & Mawani, 2023; Kumar et al., 2021). Other research has focused on the manipulation of transfer pricing and its impact on corporate behavior, particularly regarding profit shifting to tax havens, which can lead to inefficient profit allocation and increased tax evasion (Rathke et al., 2021).

Given that transfer pricing encompasses a wide range of research questions, this article aims first to identify trends in scientific interest in transfer pricing over the period 1975–2023 and subsequently to determine the geographical distribution of publications to identify the countries contributing most to the discussion on this topic.

2. Methodology

To achieve the objective, the desk research method was employed. The data sources comprised scientific research studies from the Web of Science (WOS) database, one of the most widely used scientific databases in the Czech Republic. WOS contains a broad collection of scientific articles, books, and conference proceedings, providing a comprehensive overview of scholarly literature and covering a wide range of disciplines related to transfer pricing.

The source data were selected using the keywords "transfer pricing" and its variations "transfer price" and "transfer prices." In the next step, the selection of publications was narrowed to fields such as economics, corporate finance, management, entrepreneurship, and law. Data were collected for all time periods available in WOS, spanning from 1975 to 2023, encompassing a total of 3,907 documents. First, the publications were sorted chronologically, and a timeline analysis was conducted to determine how interest in this topic evolved over time and during which periods the number of studies increased significantly, pointing to key milestones—events that triggered this growth in interest. Subsequently, the studies were sorted geographically. The data were processed using a cartogram, which identified the countries that most actively research transfer pricing and contribute to the discussion.

3. Results

Although the systematic resolution of transfer pricing issues dates back to the 1930s, the first scientific studies recorded in the WOS database appear only in 1975. Figure 1 illustrates how interest in the topic of transfer pricing has increased over the years.

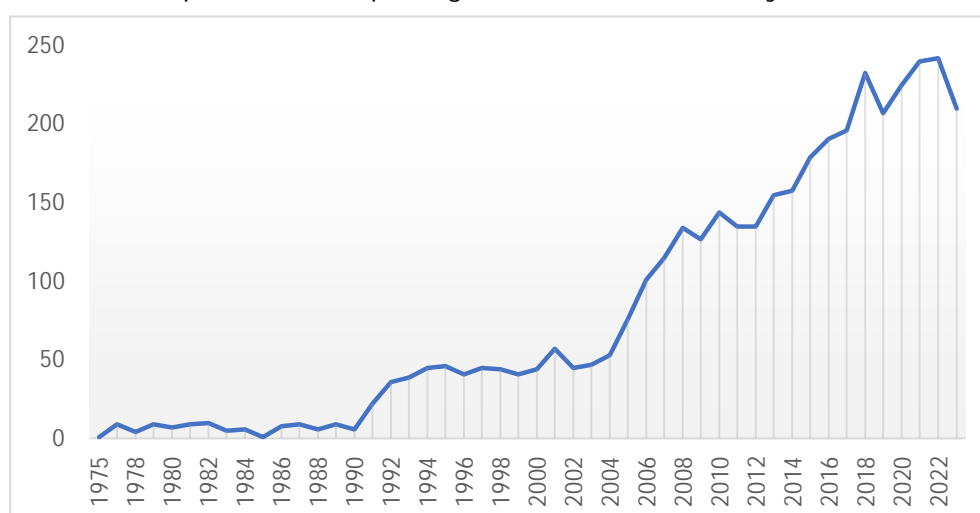


Figure 1. The development of academic interest in transfer pricing over time

The issue of transfer pricing experienced significant growth in academic interest during the years 1992, 2006, 2018, and 2021. This can be attributed to several key events and trends that influenced the regulatory framework and economic environment during these periods.

The 1990s were characterized by accelerating globalization, as multinational corporations increasingly participated in international trade, leading to a higher volume of cross-border transactions among their subsidiaries (Eden, 1998). In this context, 1992 marked a significant milestone when the OECD published the first major version of the Transfer Pricing Guidelines for Multinational Enterprises and Tax Administrations (OECD, 1992). This document established a unified framework for applying the arm's length principle, which became the cornerstone of international transfer pricing practices. The academic community responded to these changes with extensive analyses of the new rules' impacts on corporate strategies and the economies of individual countries.

The year 2006 was notable for the increased focus on transfer pricing audits by tax authorities and media scrutiny. This trend was linked to a growing number of cases where multinational corporations were accused of exploiting differences in tax systems across countries. High-profile tax disputes that captured public attention exposed gaps in existing regulations and led to stricter OECD guidelines and national legislation (Grubert & Altshuler, 2006). Simultaneously, the digitalization of commerce accelerated, with technology companies such as Google and Amazon facing debates over the proper allocation of profits among the countries where they operate (Ting, 2014).

In 2018, both scientific and regulatory interest in transfer pricing increased again due to the advanced implementation of the BEPS (Base Erosion and Profit Shifting) Action Plan, initiated by the OECD in 2013. The goal of this plan was to reduce tax evasion and aggressive tax planning by multinational corporations through stricter transfer pricing rules (OECD, 2018). Mechanisms such as country-by-country reporting (CBCR) required firms to provide detailed information about their financial transactions, creating new research opportunities (Hugger, 2019). This year also saw a significant rise in public pressure for fair taxation of technology giants, contributing to discussions about redistributing tax rights within the digital economy.

The year 2021 marked another major shift, primarily with the agreement on a global minimum tax of 15% for multinational corporations. This step was considered a historic success in combating tax avoidance and encouraged the academic community to focus on the impact of the new tax regime on transfer pricing practices (IMF, 2021). Additionally, the COVID-19 pandemic introduced further complications, disrupting global supply chains and raising questions about how to properly allocate profits and losses among the subsidiaries of multinational corporations (Cui, 2021). At the same time, the intense debate about taxing the digital economy continued, becoming a key focus of the OECD's new regulatory agenda.

The increased interest in transfer pricing during these years can thus be attributed to a combination of regulatory changes, high-profile cases of tax avoidance, growing globalization, and changes in the digital economy. These factors provided new challenges and opportunities for academic analysis, enriching the understanding of one of the most significant areas of international economics.

Transfer pricing remains primarily an academic discipline, emphasizing detailed and rigorous research published in scholarly journals. The lower representation of conference proceedings and other document types suggests that the field is more focused on long-term studies rather than the rapid dissemination of new ideas.

Figure 2 illustrates the geographical distribution of academic works on transfer pricing, showing that the largest contributors are the United States (1,322 works), followed by China (470 works), the United Kingdom (309 works), Germany (286 works), Canada (200 works), France (187 works), Australia (161 works), Italy (120 works), and the Netherlands (107 works). This distribution can be interpreted based on economic, academic, and regulatory factors influencing the focus of research in individual countries.

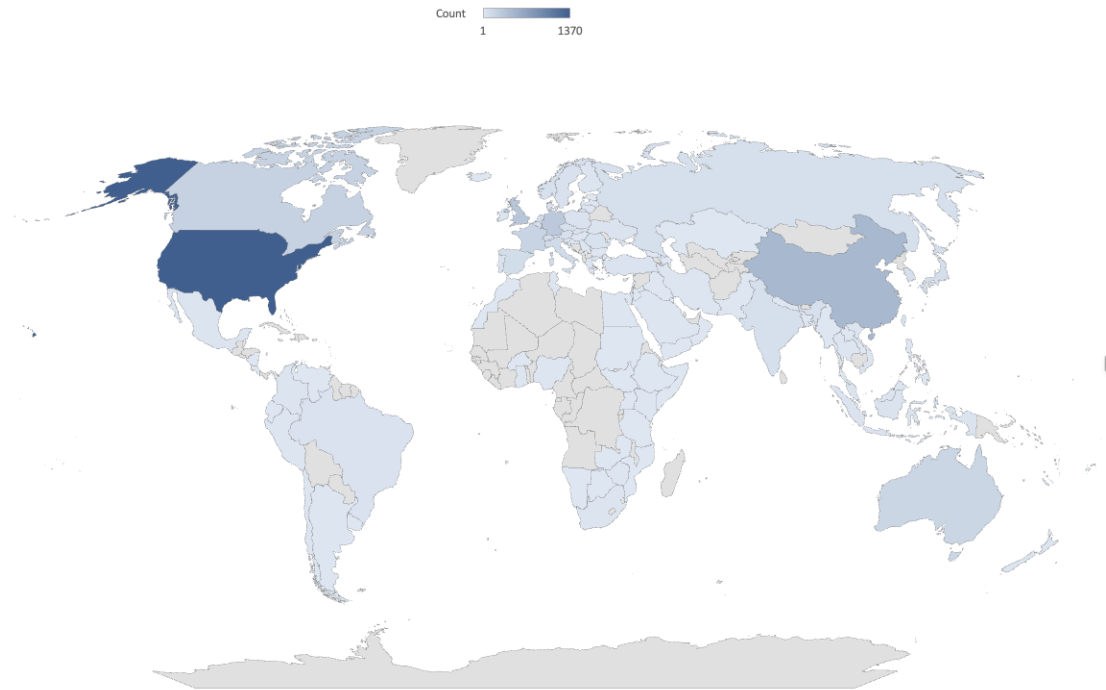


Figure 2. Geographical distribution of academic works

The United States clearly dominates transfer pricing research, which can be attributed to several key factors. The size of the U.S. economy and the presence of numerous multinational corporations, such as technology giants and pharmaceutical companies, ensure that transfer pricing is highly relevant to the country (Eden, 1998). The U.S. tax system, including recent changes like the Tax Cuts and Jobs Act of 2017, often influences international discussions on profit allocation and tax policy, driving research in this area (Gravelle, 2019). Additionally, the United States boasts an extensive network of top-tier universities with the capacity to conduct in-depth and detailed research in this field.

China ranks second, and its growing presence in scientific production reflects its position as a key player in global trade. As the primary manufacturing hub for many multinational corporations, China is deeply involved in managing transfer pricing, often driven by state regulations focused on controlling cross-border transactions (Chan & Chow, 2010). Simultaneously, as China expands globally, transfer pricing has become an increasingly significant topic for Chinese academic institutions.

European countries, including the United Kingdom, Germany, France, Italy, and the Netherlands, also play a significant role in scientific output in this field. The European Union is pivotal in shaping transfer pricing policies, particularly through OECD initiatives and the implementation of the BEPS Action Plan (OECD, 2018). European economies are often home to multinational corporations with complex supply chains, which naturally attract academic attention. For instance, Germany, as an export powerhouse, addresses issues of profit allocation among subsidiaries, while the United Kingdom focuses on the impact of transfer pricing in the context of its financial sector and post-Brexit tax policies (Crivelli et al., 2015).

Canada and Australia hold significant positions due to their integration with global value chains. Canada benefits from its proximity to the United States and shared regulatory

frameworks through agreements such as the United States-Mexico-Canada Agreement (USMCA), which heightens its focus on cross-border tax issues (Mintz & Chen, 2014). In contrast, Australia focuses on transfer pricing in relation to the rapidly growing markets of Asia and the Pacific. Its geographical location positions it as a key player in the digital economy and trade innovation (Taylor et al., 2015).

This geographical distribution of scientific production reflects the global nature of transfer pricing research and its close connection to the economic and regulatory characteristics of individual regions. Countries with robust economies and well-developed academic infrastructures, such as the United States, China, and European nations, dominate this field, while smaller countries contribute primarily in the context of their specific economic ties and regulatory interests.

4. Discussion

The presented findings confirm the importance of transfer pricing as a critical topic in international tax policy. The increase in publications during key periods, such as 1992, 2006, 2018, and 2021, clearly reflects regulatory changes and economic trends. These milestones correspond to global events, such as the introduction of OECD guidelines, the implementation of BEPS, and the agreement on a global minimum tax. This alignment indicates a strong interconnection between academic research and regulatory initiatives.

The United States dominates transfer pricing research, which corresponds to its economic size, regulatory initiatives, and top-tier academic capacity. Similarly, China and European countries such as Germany and the United Kingdom reflect their economic and academic influence in the field of transfer pricing.

Unlike the findings from the 2010s, which emphasized specific risks associated with transfer pricing compliance (Jost et al., 2014), this article focuses on broader geographical and regulatory dynamics. At the same time, the conclusions point to changes that may signal the end of the traditional concept of transfer pricing based on the arm's length principle.

Significant regulatory initiatives, such as the global minimum tax agreement and disruptions to traditional supply chains (e.g., the introduction of CBCR), suggest that the future of transfer pricing is moving toward the implementation of a global profit allocation method. This approach could replace the current model based on individual transactions, aiming for a fairer allocation of tax revenues across jurisdictions. Such a shift could establish a new standard in international tax policy and create more efficient tax systems for multinational corporations. As noted by Kumar et al. (2021), the current developments in transfer pricing increasingly highlight the need for global reforms and improved rules to address tax planning challenges and contribute to more transparent and equitable tax systems.

5. Conclusions

The timeline analysis identified an increase in academic interest in the topic of transfer pricing over the years, which can be attributed to several key events and trends that influenced the regulatory framework and economic conditions during these periods.

Geographical analysis identified the United States as the largest contributor to this field, followed by China and several European countries. This result reflects the significant role of these regions in the global economy and academic research. The article thus provides a comprehensive overview of the development of trends and achieves its goal of identifying the factors influencing scientific activity in the area of transfer pricing.

The findings also raise new questions for future research. Potential directions for further investigation include a deeper analysis of the role of emerging markets, the impact of technological changes on transfer pricing, and ways in which regulatory policies can contribute to a fairer allocation of tax revenues among countries.

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Conflict of interest: none

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Financial Asset Planning Evaluation: A Systematic Review of Portfolio Structures and Investment Decision-Making Models

Michal ZILVAR

University of Hradec Kralove, Hradec Kralove, Czechia; michal.zilvar@uhk.cz

Abstract: Financial asset planning plays a critical role in long-term wealth management and investment decision-making. However, financial planning models often lack empirical validation, raising concerns about their applicability in real-world advisory contexts. This study conducts a systematic literature review using the SPAR-4-SLR framework to evaluate the extent to which financial planning models have been empirically tested. A structured search in Scopus, Web of Science, and ScienceDirect identified 97 studies, of which only nine met the inclusion criteria. The results reveal that while financial planning models are widely discussed in theoretical literature, empirical research remains limited, with only two studies classified as explorative and the majority being confirmative, indicating a lack of studies aimed at developing new frameworks. The findings highlight key gaps, including a lack of experimental studies, geographic limitations, and the exclusion of certain financial sectors. Additionally, regulatory and compensation differences across countries influence the application of financial planning models and affect their effectiveness. This review contributes to the discourse on evidence-based financial planning by identifying areas requiring further research, particularly regarding behavioral influences on financial decision-making. Strengthening the empirical foundation of financial planning models is essential for enhancing their practical implementation and academic development.

Keywords: financial asset planning; investment decision-making; portfolio management; behavioral finance; systematic literature review; empirical validation

JEL Classification: G11; D14; G40

1. Introduction

Financial asset planning plays a crucial role in long-term wealth management, guiding individuals in making informed investment decisions. Traditionally, financial planning success has been evaluated subjectively, with advisors relying on their professional judgment to assess whether clients' financial goals have been met (Yeo et al., 2024). However, subjective evaluations lack consistency, transparency, and replicability, leading to potential biases and discrepancies in financial advisory practices. In response, financial behavior research has increasingly emphasized structured and empirically validated models to assess financial planning outcomes.

One such approach is the Theory of Financial Planning Behavior, which expands upon the Theory of Planned Behavior (TPB) by integrating behavioral finance elements into

financial decision-making (Yeo et al., 2024). These models propose that attitudes, subjective norms, and perceived behavioral control shape financial planning behaviors, influencing decisions across key areas such as cash flow, investments, risk, and retirement planning. While these models offer a structured framework, it remains unclear whether they have been adequately tested in real-world settings, raising questions about their empirical validation and practical applicability.

The structure and regulation of financial advisory services vary significantly across countries, further influencing financial planning approaches. In markets such as the United States and the United Kingdom, financial advisors predominantly operate under a fee-based compensation model, where advisors charge clients directly for financial planning services. This model is increasingly favored due to its alignment with goal-based financial planning and reduced conflicts of interest (Wood, 2023). In contrast, commission-based financial advisory models dominate in markets such as the Czech Republic, where advisors primarily generate revenue from the sale of mortgages, loans, and insurance products. Investment advisory services, despite their significance in long-term financial planning, are often underdeveloped and underestimated in such markets (AssetMark, 2022). Regulatory measures in some countries, such as the Czech Republic, prohibit the combination of voluntary payments and commission-based compensation to mitigate conflicts of interest (Angelova & Regner, 2013; Sokolinski, 2023). These structural differences impact how financial planning models are applied and whether they effectively contribute to financial decision-making.

Given these variations and the growing emphasis on evidence-based financial planning, this study seeks to address two key research questions:

- *RQ1: Does the existing body of literature on financial planning behavior provide sufficient empirical evidence to validate theoretical models?*
- *RQ2: Have these models been tested in at least two financially developed countries with stable market economies to assess their applicability?*

To answer these questions, this paper employs the SPAR-4-SLR framework to systematically evaluate financial planning models and their empirical validation. By analyzing existing research, this review aims to identify strengths, gaps, and limitations in financial planning literature while offering insights into its practical implications for financial advisors and policymakers.

2. Methodology

To systematically evaluate the existing research on financial planning models and the factors influencing financial decision-making, this study follows the SPAR-4-SLR (Scientific Procedures and Rationales for Systematic Literature Reviews) framework, as proposed by Paul et al. (2021). This methodology ensures a structured, transparent, and replicable approach to reviewing academic literature by emphasizing scientific rigor, clear procedural guidelines, and justification for methodological decisions.

A key reason for adopting this framework is its prior application in the study by Yeo et al. (2024), which served as a foundation for this research. Their systematic literature review on financial planning behavior utilized the SPAR-4-SLR methodology to synthesize existing models and identify gaps in empirical validation. Given the study's relevance to financial planning theories and its structured approach to reviewing behavioral finance literature, applying the same methodological framework ensures consistency and allows for a comparative analysis of findings in this research.

While PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a widely used framework for systematic reviews, it is primarily designed for healthcare and medical sciences, focusing on randomized controlled trials and quantitative synthesis (Page et al., 2021). In contrast, SPAR-4-SLR provides a more flexible and comprehensive approach, making it particularly well-suited for reviews in social sciences, including finance and behavioral economics. SPAR-4-SLR emphasizes scientific rigor while allowing for the integration of conceptual, exploratory, and confirmatory studies—essential for analyzing financial planning models. Its structured process ensures transparency and replicability while maintaining adaptability for diverse research designs, making it a more appropriate choice for this study.

Framework SPAR-4-SLR consists of four key phases—Setup, Search, Appraisal, and Synthesis—which provide a structured yet adaptable process for systematically identifying, evaluating, and synthesizing relevant literature. By following these steps, this review ensures methodological rigor while allowing for a comprehensive analysis of financial planning models and the behavioral factors influencing financial decision-making.

1. Setup: The research scope was defined to focus on financial planning models, their empirical validation, and the behavioral factors influencing financial decisions. The review targeted peer-reviewed articles published within the last 10 years, primarily in financially developed countries (e.g., USA, UK, Europe, China, Japan). The databases selected for the search were Web of Science, Scopus, and ScienceDirect, ensuring comprehensive coverage of high-impact journals.
2. Search: A structured search strategy was implemented using Boolean operators and targeted keywords. The main search query was:

("financial planning" AND "behavioral finance" AND "financial decision-making")

Additional refinements included alternative terms such as "financial planning models", "psychological factors in financial planning", and "empirical testing of financial behavior" to improve relevance. The initial search retrieved 45 articles from ScienceDirect, 8 from Scopus, and 49 from Web of Science, which were further screened for relevance.

3. Appraisal: Titles and abstracts were reviewed to exclude studies that were not directly related to financial asset planning, portfolio structures, and investment decision-making. To maintain relevance, the selection of peer-reviewed papers was based on the following citation criteria in Table 1.

Table 1. Minimum citations required by the publication date

Publication Date	Minimum Citations Required
January 1, 2014 – July 1, 2024	5
July 1, 2024 – December 31, 2024	1
January 1, 2025 and Later	0

This ensures that older studies have demonstrated academic impact, while newer studies are still considered based on their timeliness and potential contributions to financial asset planning and investment research. Additionally, studies were excluded if they focused on any from the Table 2.

Table 2. Exclusion criteria applied to unwanted studies

General financial literacy, unless directly linked to investment decisions or portfolio management.
Household budgeting, consumption, and savings behavior, unless relevant to financial asset allocation.
Behavioral finance research unrelated to capital markets, such as psychological biases not influencing investment decisions.
Retirement planning studies, unless they focus on investment portfolio management.
Insurance & pensions, unless they are part of a broader investment strategy.
Corporate finance & firm-level studies, as the focus is on individual financial planning.
Non-market financial decision-making, such as charitable giving and financial socialization.
SMEs & entrepreneurship finance, as the focus is on individual investment behavior.
Islamic finance, as the research is limited to conventional financial markets.
Markets outside the USA, UK, Europe, China, and Japan, to maintain focus on developed financial markets.

This refined selection process ensures that the included studies contribute meaningfully to understanding financial asset planning, portfolio structures, and investment behaviors within financially developed economies.

4. Synthesis: The selected studies were categorized into three main groups: 1) Models supported by experiments; 2) Models based on empirical data; 3) Theoretical models. Each model was further classified as explorative, confirmative, or conceptual based on its research purpose. A literature review matrix was developed to systematically compare findings across studies.

To provide a clear overview of the search and screening process, a flowchart (Figure 1) was developed following the SPAR-4-SLR methodology. This diagram illustrates the step-by-step progression from the initial identification of studies across Web of Science, Scopus, and ScienceDirect to the final selection of relevant articles for synthesis.

Initially, a total of 102 articles were identified across the three databases. After removing duplicates, studies were screened for relevance based on title, abstract, and keywords, with exclusions made for articles that:

- Focused on SMEs, non-market financial decision-making, or Islamic finance.
- Were outside the scope of financial asset planning, portfolio structures, and capital markets.
- Covered corporate finance, insurance, pensions, or retirement planning without direct relevance to investment strategies.

- Examined general financial literacy or behavioral finance without a connection to investment decision-making.
- Were conducted in non-financially developed countries (outside the USA, UK, Europe, China, and Japan).
- Were non-peer-reviewed or did not meet the citation threshold (at least five citations for papers older than one year, no citation requirement for recent papers).

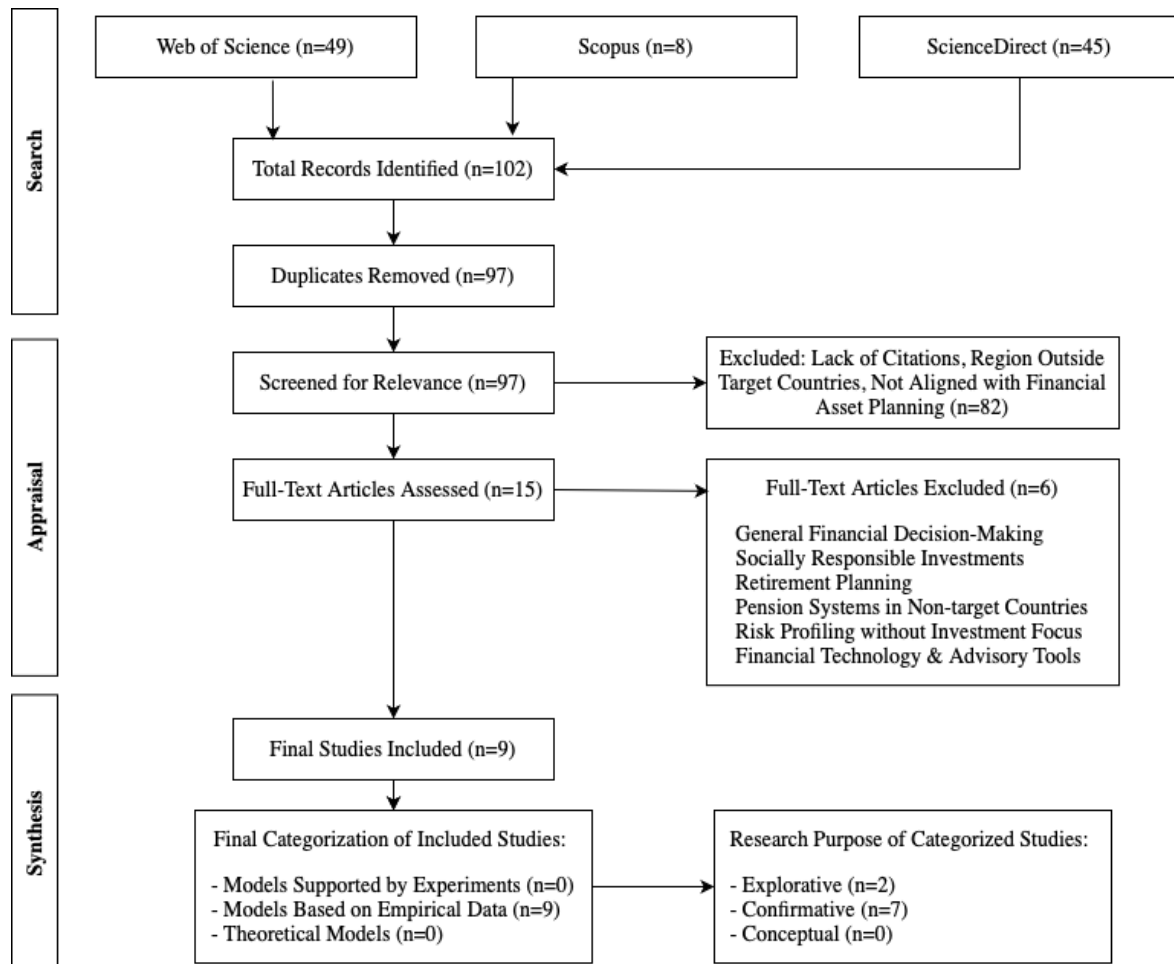


Figure 1. Systematic literature review process using the SPAR-4-SLR framework

Full-text screening was then conducted to ensure alignment with the study's refined scope, selecting only studies that contribute directly to understanding financial asset planning, portfolio structures, investment behaviors, and capital markets.

Following the appraisal process, only studies that explicitly addressed financial asset planning, portfolio structures, empirical validation of investment models, and behavioral decision-making in capital markets were retained.

The final selection of studies was categorized based on their methodological approach, distinguishing between:

- Models supported by experiments;
- Models based on empirical data;
- Theoretical models.

Each study was further classified as explorative, confirmative, or conceptual, ensuring a systematic comparison of financial asset planning models and their underlying behavioral factors. This structured categorization enables a nuanced synthesis of existing research, highlighting key theoretical contributions and empirical evidence in investment decision-making and financial planning.

3. Results

The systematic screening process resulted in a final selection of nine studies, after multiple exclusion stages. Initially, 97 papers were identified, but 82 were excluded due to lack of citations or misalignment with the study's scope. A further six studies were removed during full-text review for focusing on general financial decision-making, retirement planning, or non-target financial markets rather than financial asset planning and portfolio structures. The retained studies were then categorized based on their methodological approach and research focus, distinguishing between empirical, experimental, and theoretical models as well as explorative, confirmative, and conceptual research purposes. Table 3 provides a structured synthesis of these studies, highlighting their contributions to understanding financial asset planning, portfolio management, and investment decision-making.

The systematic review identified nine empirical studies, of which two were explorative and seven were confirmative. The explorative studies aimed to uncover new behavioral relationships in financial planning, while the confirmative studies tested and validated existing financial planning models. Despite differences in research scope, several commonalities emerged.

3.1. Behavioral Influences on Investment Decisions

A recurring theme among the selected studies is the role of behavioral biases and psychological factors in financial decision-making. Dima et al. (2025) and Pak and Chatterjee (2016) both examined risk perception and investor biases, but from different perspectives. While Dima et al. (2025) analyzed how past volatility influences future investment expectations, Pak and Chatterjee (2016) focused on overconfidence bias in aging investors, showing how excessive confidence leads to higher risk-taking in retirement portfolios.

Similarly, Hemrajani et al. (2023) and Thanki et al. (2024) explored financial risk tolerance and behavioral drivers of investment choices. Hemrajani et al. (2023) conducted a systematic review of risk tolerance literature, while Thanki et al. (2024) applied the Theory of Planned Behavior (TPB) to assess how social norms and financial literacy influence mutual fund investments. Despite different approaches, both studies highlighted the importance of external influences on investment behavior, emphasizing the need for financial education and targeted advisory strategies.

Table 3. Categorization of selected studies on financial asset planning and investment decision-making

Study (Author, Year)	Model Type (Experiment, Empirical, Theoretical)	Research Purpose (Explorative, Confirmative, Conceptual)	Scientific Gap	Relevance to Financial Planning
Dima et al. (2025)	Empirical	Explorative	Lack of models integrating past volatility in predictive frameworks for financial planning.	Highlights the impact of past volatility on current trading decisions.
Hemrajani et al. (2023)	Empirical	Explorative	Absence of cross-cultural assessments and neuroscientific insights into financial risk tolerance.	Enhances understanding of risk tolerance for tailored financial strategies.
Pak and Chatterjee (2016)	Empirical	Confirmative	Weak empirical link between overconfidence and portfolio allocation; limited longitudinal data.	Highlights cognitive biases' impact on financial planning among older adults, analyzed using a two-part regression model.
Shanmuganathan (2020)	Empirical	Confirmative	Insufficient research on robo-advisors' performance in volatile markets; limited user experience studies.	Highlights the role of robo-advisors in optimizing portfolio management and influencing investment decisions.
Tarkom and Ujah (2023)	Empirical	Confirmative	Lack of research on long-term effects of economic policy uncertainty across different industries.	Contributes to understanding how external uncertainties influence financial asset planning and working capital management.
Thanki et al. (2024)	Empirical	Confirmative	Overemphasis on individual behavioral factors; lacks structural financial conditions analysis.	Highlights the role of social influences and financial literacy in investment intentions, informing investor education strategies.
Ullah et al. (2024)	Empirical	Confirmative	Limited research on AI-based financial decision-making beyond individual investors; lacks institutional perspective.	Highlights the role of AI in enhancing investment decision-making and portfolio management.
Wang et al. (2019)	Empirical	Confirmative	Limited empirical validation of credit risk contagion models across different market conditions.	Highlights the importance of investor behavior in mitigating credit risk for effective portfolio management.
Zhu et al. (2024)	Empirical	Confirmative	Lack of empirical studies on post-adoption behaviors of robo-advisors and ethical implications.	Provides insights into integrating robo-advisors into financial planning and emphasizes customer trust.

3.2. Technology and Financial Planning: AI and Robo-Advisors

Three studies examined AI-driven financial advisory services, revealing both potential benefits and limitations. Shanmuganathan (2020) and Zhu et al. (2024) focused on robo-advisors, finding that AI-driven platforms enhance efficiency and reduce costs but lack personalized financial guidance. Ullah et al. (2024) expanded this discussion by analyzing ChatGPT's role in investment decision-making, showing that AI tools improve financial strategies when combined with financial literacy. However, all three studies emphasized that robo-advisors and AI-driven tools cannot fully replace human financial advisors, especially in areas requiring personalized financial planning and emotional intelligence.

3.3. Financial Risk and Market Uncertainty

Risk management and market uncertainty were central themes in several studies. Tarkom and Ujah (2023) analyzed how global economic policy uncertainty (GEPU) affects working capital management, finding that firms in risk-averse cultures adopt more conservative financial strategies. Wang et al. (2019) examined credit risk contagion in financial markets, showing how investor behavior and information disclosure impact systemic risk. Both studies highlight the importance of risk perception and financial stability, though one focuses on corporate financial strategies while the other examines credit market stability.

3.4. Scientific Gaps and Future Research Directions

Across all studies, several scientific gaps emerged:

- Limited cross-country validation – Most studies were geographically constrained, with some focused on a single market, e.g. Ullah et al. (2024) in Pakistan, Thanki et al. (2024) in India, raising concerns about generalizability. Future research should focus on testing financial planning models across multiple stable economies.
- Lack of experimental studies – The majority of studies were confirmative, with only two explorative studies aiming to develop new frameworks. This suggests that financial planning research prioritizes validation over innovation.
- Unexplored technological implications – While several studies examined AI in financial planning, long-term effects of robo-advisors and AI-driven decision-making remain under-researched, particularly concerning ethical considerations, customer trust, and regulatory adaptation.
- Behavioral finance integration – Several studies highlighted investor biases, but few explored how financial advisors can actively mitigate these biases through structured interventions.

By synthesizing these findings, this review highlights the need for broader empirical validation, cross-market comparisons, and innovative financial planning models to enhance both academic research and practical applications.

4. Discussion

The findings of this review highlight both the strengths and limitations of empirical research on financial planning models. While financial planning models are widely discussed in theoretical literature, empirical validation remains limited, with only nine studies meeting the inclusion criteria. This suggests that financial planning models often lack rigorous testing in real-world settings, raising concerns about their practical applicability.

4.1. Empirical Validation of Financial Planning Models (RQ1)

The first research question *RQ1: Does the existing body of literature on financial planning behavior provide sufficient empirical evidence to validate theoretical models?* can be partially answered. The review found that while confirmative studies provide empirical support for existing models, only two studies were explorative, indicating a lack of research aimed at developing new frameworks. This imbalance suggests that the field of financial planning prioritizes validation over innovation, potentially limiting the development of more adaptable, behaviorally informed models. Furthermore, most studies rely on observational data rather than experimental research, reducing the ability to establish causal relationships in financial decision-making.

Pak & Chatterjee (2016) and Thanki et al. (2024) both examined behavioral influences on financial decision-making, yet from different perspectives. Pak & Chatterjee (2016) linked overconfidence bias to risk-taking in older investors, while Thanki et al. (2024) found that social norms have a stronger effect on investment behavior than financial literacy. These findings indicate that multiple behavioral drivers shape financial decisions, suggesting the need for a more integrated financial planning model that considers cognitive biases, social influences, and financial literacy simultaneously.

4.2. Applicability Across Diverse Financial Markets (RQ2)

The second research question *RQ2: Have these models been tested in at least two financially developed countries with stable market economies to assess their applicability?* reveals additional concerns. Financial planning behaviors are shaped by regulatory frameworks, compensation models, and investor preferences, which vary across markets. While some studies focused on developed financial markets, e.g. the United States and the United Kingdom, others were geographically constrained raising concerns about generalizability, e.g., Thanki et al. (2024) in India, Ullah et al. (2024) in Pakistan.

The studies by Dima et al. (2025) and Tarkom & Ujah (2023) both investigated market uncertainty and financial decision-making, yet their approaches differed significantly. Dima et al. (2025) examined how past volatility influences future trading expectations, while Tarkom & Ujah (2023) focused on how firms adjust working capital strategies in response to economic policy uncertainty. These studies reinforce the idea that both individual and corporate financial planning are influenced by external economic shocks, but existing financial planning models fail to fully integrate investor reactions to uncertainty.

Similarly, Shanmuganathan (2020), Ullah et al. (2024), and Zhu et al. (2024) all explored the role of AI and robo-advisors in financial planning, yet their conclusions varied.

Shanmuganathan (2020) found that robo-advisors improve investment performance, but Zhu et al. (2024) emphasized that they lack personalization and emotional intelligence, limiting full adoption. Ullah et al. (2024) further expanded this discussion by assessing ChatGPT's role in investment decisions, showing that AI tools can enhance portfolio management, but their impact is highly dependent on financial literacy levels. These findings suggest that while AI-driven financial planning is promising, its success is contingent on investor trust, regulatory frameworks, and financial education.

4.3. Key Themes and Scientific Gaps

Several major themes emerged across the reviewed studies:

- Behavioral influences on financial decision-making – Studies confirm that psychological biases, e.g. overconfidence, risk perception, and social influences, play a critical role in investment strategies, yet few models integrate multiple behavioral factors.
- Technology in financial planning – While robo-advisors and AI-driven financial tools enhance efficiency, their lack of personalization and regulatory oversight raises questions about their long-term adoption.
- Financial risk and market uncertainty – Economic shocks and investor reactions significantly influence financial planning, but existing models do not fully capture these dynamics in different financial systems.

By synthesizing these insights, this review highlights gaps in cross-country validation, experimental research, and behavioral finance integration, reinforcing the need for broader, empirically grounded financial planning models.

5. Conclusions

The objective of this study was to systematically evaluate the empirical validation of financial planning models and assess their applicability in real-world financial decision-making. Using the SPAR-4-SLR framework, this review synthesized research on financial asset planning, portfolio structures, and investment behavior. However, the findings indicate a notable gap in empirical studies supporting financial planning models, with only nine studies meeting the inclusion criteria. Among these, two were explorative, uncovering new behavioral relationships, while the remaining seven were confirmative, testing and validating existing theoretical models.

These findings suggest that, while financial planning models are well-established in theory, their empirical validation remains limited. The first research question (RQ1) examined whether the existing body of literature provides sufficient empirical evidence to validate financial planning models. The results indicate that confirmative studies reinforce existing models, but the lack of explorative and experimental research limits the development of new, behaviorally informed frameworks. This imbalance suggests a research gap in testing alternative financial planning strategies, particularly those integrating psychological and technological factors into decision-making.

The second research question (RQ2) addressed whether financial planning models have been tested across multiple financially developed countries to assess their applicability. The findings revealed that few studies conducted cross-national empirical validation, with many focused on single-market datasets. This raises concerns about the generalizability of financial planning models, as investor behavior is shaped by regulatory frameworks, economic stability, and cultural influences. Future research should prioritize cross-country validation to assess whether these models remain applicable across diverse financial systems.

Despite its contributions, this review has certain limitations. The selection criteria prioritized peer-reviewed empirical studies, excluding industry reports and policy analyses, which may offer complementary insights. Additionally, the focus on developed financial markets means that financial planning behaviors in emerging economies remain underexplored. Furthermore, the absence of experimental research in the reviewed studies suggests that future studies should employ controlled experiments and mixed-method approaches to enhance the causal understanding of financial decision-making.

By identifying gaps in empirical research and highlighting areas requiring further study, this review contributes to the ongoing discourse on evidence-based financial planning. Strengthening the empirical foundation of financial planning models through broader geographic representation and innovative methodologies is essential for developing adaptable, behaviorally informed frameworks that enhance both academic research and practical financial advisory services.

Conflict of interest: none

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