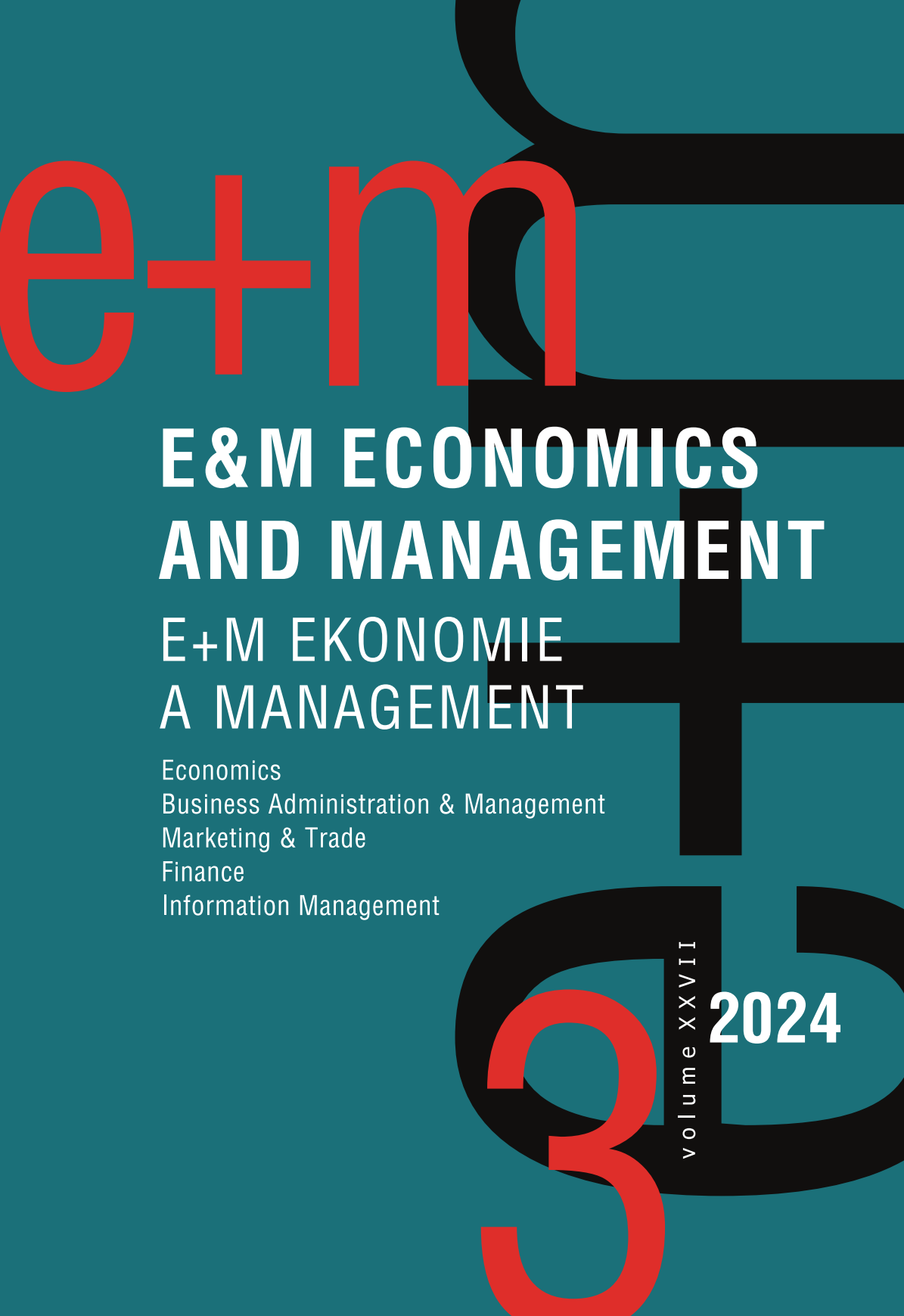
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Contents

Editorial – Emerging digital technologies and their influence on elimination of supply chain vulnerability

The past few years have seen significant disruptions affecting global supply chains, from the COVID-19 pandemic to geopolitical conflicts and climate change. These events have highlighted the vulnerabilities within supply chains, causing widespread delays, capacity limitations, and disrupted deliveries. In response, both the scientific community and industry practitioners have been actively seeking innovative solutions to enhance the resilience and efficiency of supply chains. One of the most promising avenues is the integration of emerging digital technologies.

This issue of E&M Economics and Management aims to expand the understanding of how digital technologies can be leveraged to mitigate supply chain vulnerabilities. The focus is on exploring the role of these technologies in making supply chains more lean, agile, resilient, and environmentally sustainable. The collected articles offer a comprehensive look into various aspects of this dynamic field.

The article “Navigating urban logistics challenges: An optimized approach to parcel distribution in the Prague city center,” by Jakub Andar, Kateřina Hušková, and Jakub Dyntar, explores innovative strategies for optimizing parcel distribution in urban environments, focusing on Prague’s city center. In “Information and communication technology diffusion, supply chain performance, health care and human development: A case of the South Asian region,” Minhas Akbar, Ammar Hussain, Marina Nazir, Petra Poulová, and Jiashun Huang examine the impact of ICT diffusion on supply chain performance and its broader effects on health care and human development in South Asia. “The nexus between logistics competitiveness, logistics carbon emission efficiency, and industrial structure upgrading: Evidence from China,” by Guanglan Zhou, Yulian Fei, and Chengkai Feng, investigates the interplay between logistics competitiveness and carbon emission efficiency in China, emphasizing the role of industrial structure upgrading. Luay Jum’a and Dina Alkhodary, in their article “Navigating the Industry 4.0 frontier: Unveiling perceived risk and cost moderators in technology adoption,” analyze the challenges and opportunities of adopting Industry 4.0 technologies, focusing on perceived risks and cost factors. The article "Existing and forthcoming obstacles in adopting technological advances in vulnerable supply chains," by Rohit Raj, Vimal Kumar, Jyoti Ranjana, and C. Anirvinna, identifies key indicators that influence the adoption of new technological advancements to enhance supply chain operations using the grey relational analysis (GRA). Finally, “Navigating the human element: Unveiling insights into workforce dynamics in supply chain automation through smart bibliometric analysis,” by Melanie Angielski, Lukáš Copuš, Peter Madzík, and Lukáš Falát, provides a comprehensive analysis of workforce dynamics in the context of supply chain automation, using advanced bibliometric methods.

The articles in this issue collectively underscore the transformative potential of digital technologies in addressing supply chain vulnerabilities. They explore various dimensions, from optimizing urban logistics to leveraging ICT for improved supply chain performance and human development. They investigate the dynamic relationship between logistics competitiveness and carbon emission efficiency, analyze the challenges of Industry 4.0 adoption, and delve into workforce dynamics in the context of supply chain automation. These diverse studies offer robust solutions and insights for contemporary supply chain challenges. As the field continues to evolve, further research and practical applications will be essential in fully realizing the benefits of digital transformation in supply chains.

We hope this issue provides valuable insights and stimulates further research and discussion on the role of emerging digital technologies in creating lean, agile, resilient, and green supply chains.

Guest editors

Dominik Zimon, Professor at Rzeszów University of Technology, Poland
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Navigating urban logistics challenges: An optimized approach to parcel distribution in the Prague city center

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Abstract: *In this paper, we focus on metropolitan transport logistics that has always been difficult due to the need to transport goods through a complex urban infrastructure, heavy traffic, and dense populations. The goal of this paper is to describe a micro hub location in the neighborhood of the historic center of the city of Prague, the Czech Republic in a situation where the municipalities consider prohibiting the entry of trucks with combustion engines that currently provide cargo transportation for B2B partners operating in this area. Micro hubs represent the efficient last mile consolidation and distribution facilities located in or near urban neighborhoods and serving a spatially limited, densely populated delivery area. We propose a solution combining facility location problem, vehicle routing problem and balancing with the horizontal and vertical cooperation in supply chains to locate the micro hub in the area with extremely low availability of suitable space while respecting the necessity to connect this facility to an existing network of regional terminals operated by 3PLs to ensure the distribution of cargo across the board according to the requirements of customers. For the collection and distribution of parcels within the area, we suggest to use of cargo bikes and electric vans to provide environmentally sustainable service and minimize the harmful consequences of excessive traffic for residents. We also discuss the economic implications of adopting such innovative sustainable supply chain solutions for involved horizontal and vertical supply chain partners emphasizing different motivation aspects to convince these partners to cooperate and share scarce resources.*

Keywords: *Sustainable supply chain management, horizontal and vertical supply chain cooperation, urban parcel logistics, micro hubs, facility location problem.*

JEL Classification: *M21, R410, C610.*

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Introduction

Sustainable supply chain management is becoming increasingly important for companies around the world. Businesses recognize that their supply chain decisions have ethical and environmental aftermath in addition to financial impacts. As a framework for managing a sustainable supply chain, the idea of a triple bottom line has emerged, which takes economic, social, and environmental considerations into account when making business decisions (Rahman et al., 2023). The deployment of innovative solutions that could contribute to this strategy becomes a top priority in this scenario.

In this paper, we focus on metropolitan transport logistics, which has always been difficult due to the need to transport goods through complex urban infrastructure, heavy traffic, and dense populations. Customers dispersed across cities require extensive truck detours to collect, transport, and deliver shipments. Moreover, the recent e-commerce boom has exacerbated an already serious urban logistics problem. According to World Economic Forum (2020), by 2030, the number of deliveries in the 100 largest cities on Earth is expected to increase by 78%, resulting in a 36% increase in the number of vehicles. As a result, cities will undoubtedly bear a heavy environmental burden. If nothing is done, the increase in urban logistics requirements is expected to lead to an increase in emissions of more than 30%.

Several operational strategies, such as optimizing truck routes, have been proposed to limit the number and length of detours, but they are not able to significantly reduce the traffic problem because trucks have to transport all items for the next task as per customer requirements (Cattaruzza et al., 2017). The very same customers, on the other hand, put pressure on municipalities to restrict the excessive traffic load, e.g., through a tolling or even through a complete ban on vehicles with a combustion engine in a city center. This forces the transport operators to find innovative solutions, enabling them to serve these specific locations. One such innovative approach represents micro hubs, the small distribution centers strategically located in the close neighborhoods of problematic metropolitan areas. Micro hubs can be used to facilitate last mile delivery and reduce the negative environmental and social consequences of the business (Dupas et al., 2023). Together with an ongoing electrification of transportation, this concept is of great interest to both researchers and practitioners.

The goal of this paper is to describe a micro hub location in the neighborhood of the historic center of the city of Prague, the Czech Republic. Speaking about specific city districts, the municipalities of Prague 1, 2, and 3 are considering prohibiting the entry of trucks with combustion engines that currently provide cargo transportation for B2B partners operating in this area. Until the electrification of road transport advances enough to make better economic sense to the providers of services in logistics (3PLs) micro hubs may represent the efficient way to deal with this significant change. In our opinion, there are two main challenges associated with locating a micro hub in this area. One of them is represented by the extremely low availability of suitable spaces for such a facility taking into account that the location of the micro hub is still expected to be in the very city center where residents are not willing to accept this kind of business activity. The second problem lies in connecting micro hubs to an existing network of terminals operated by 3PLs to ensure the distribution of cargo across the board according to the requirements of customers. As these local conditions are quite specific for a certain application, we examine the facility location problem rather from a management point of view than a solely operations research problem which is covered by a relatively robust body of the scientific literature. More specifically, we describe how the location of the micro hub is determined based on horizontal and/or vertical cooperation in supply chains. Thus, in this paper, we try to bridge the gap between science and real-life applications and provide readers with an insight into how businesses adopt innovative supply chain solutions to achieve financially, socially, and environmentally sustainable results.

The rest of this article is organized as follows. First, we summarize the basic features of sustainable supply chain management emphasizing the role of vertical and horizontal cooperation in reaching fair business results while satisfying customer requirements. Then, we describe the micro hub location problem, taking into account the low availability of suitable space in the area and the necessity to connect the hub with a regional terminal for the across-the-board distribution of cargo. Subsequently, we present the outputs and discuss

the benefits of the proposed solution. Finally, we conclude the paper.

1. Theoretical background

Sustainable supply chain management is a critical aspect of modern business practices. It involves integrating environmental, social, and economic considerations into the management of supply chains to minimize negative impacts and promote long-term sustainability (Dubey et al., 2017). The concept of sustainable supply chain management has gained increasing attention in recent years, with researchers exploring frameworks and practical ideas for its implementation (Taskhiri, 2016). One key aspect of sustainable supply chain management is the consideration of social issues and stakeholder engagement. Research has shown that the social dimension of sustainable development and its impact on supply chains has received less attention compared to the environmental dimension (Yawar & Seuring, 2015). However, companies must report on their responsible supply chain management, social performance, and sustainable innovations to their stakeholders (Camilleri, 2017). Environmental considerations are another crucial component of sustainable supply chain management. Green supply chain management practices, such as the adoption of green products, green manufacturing processes, and green supply chain practices, can promote environmentally sustainable business (Zhao et al., 2022). These practices can help decrease ecological risks, increase environmental efficiency, and expand market share (Almasarweh, 2022). Furthermore, sustainable supply chain management can have a positive impact on firm performance. Several studies have shown that corporate social responsibility and green supply chain management can improve firm performance (Novitasari & Agustia, 2022; Novitasari et al., 2022).

Horizontal and vertical cooperation are important aspects of sustainable supply chain management. Horizontal cooperation refers to collaboration among organizations at the same level of the supply chain, such as logistics service providers, to optimize logistics operations and enhance sustainability (Zhang et al., 2023). This type of collaboration can lead to improved efficiency, reduced costs, and minimized environmental impacts. By working together, organizations can share resources, consolidate shipments, and implement joint initiatives to promote sustainability throughout the supply chain. Vertical cooperation, on the other hand, involves collaboration between organizations at different levels of the supply chain, such as suppliers, manufacturers, and retailers. It focuses on integrating the entire supply chain from raw materials to final customers to ensure the quality of products and the performance of operational processes (Seuring & Müller, 2008). Vertical cooperation enables organizations to align their sustainability goals, share information, and coordinate activities to achieve sustainable outcomes. It can lead to improved transparency, traceability, and social and environmental performance across the supply chain. Driving forces for cooperation in sustainable supply chain management can be attributed to several factors. One key driving force is the need for improved efficiency and cost reduction. Collaboration among supply chain partners can lead to streamlined processes, reduced waste, and optimized resource utilization, resulting in cost savings for all parties involved. By working together, organizations can pool their resources, share expertise, and leverage economies of scale, leading to improved operational efficiency and reduced costs (Katsaliaki et al., 2023). Another driving force is the increasing demand for sustainability and corporate social responsibility. Consumers and stakeholders are placing greater emphasis on sustainable practices, and organizations are recognizing the importance of integrating sustainability into their supply chain operations. Collaboration allows organizations to collectively address sustainability challenges, such as reducing carbon emissions, minimizing waste, and promoting ethical sourcing (Zhou & Wang, 2021). By cooperating, organizations can share best practices, develop joint initiatives, and drive sustainability improvements throughout the supply chain. Furthermore, regulatory requirements and industry standards play a significant role in driving cooperation in sustainable supply chain management. Governments and regulatory bodies are implementing stricter environmental and social regulations, which require organizations to comply with sustainability standards (Oh et al., 2020). Collaboration among supply chain partners can help ensure compliance with these regulations and standards, as well as facilitate knowledge sharing and capacity building. By working together,

organizations can navigate complex regulatory landscapes and meet the evolving sustainability expectations of customers and regulators. Technology and information sharing also serve as driving forces for cooperation in sustainable supply chain management. Advances in information and communication technology have made it easier for organizations to share data, collaborate on planning and forecasting, and coordinate their activities (Hollmann et al., 2015). Collaborative platforms and tools enable real-time information sharing, visibility, and traceability, which are crucial for sustainable supply chain management. By leveraging technology and sharing information, organizations can enhance transparency, traceability, and accountability in their supply chains, leading to improved sustainability performance.

Collaboration and cooperation among stakeholders have become crucial for the success of sustainable urban parcel logistics as well. This includes collaboration between businesses, logistics service providers, citizens, and the public sector (Patella et al., 2020). Stakeholder involvement and engagement in the planning and implementation process are essential to ensure that solutions are tailored to the specific needs and characteristics of each urban area. Collaborative efforts can lead to the development of innovative solutions, such as shared micro depot networks and dynamic pooled capacity deployment, which optimize resources and reduce environmental impacts (Faugère et al., 2022; Hribernik et al., 2020). Marujo et al. (2018) state that micro hubs represent an efficient last-mile consolidation and distribution facility located in or near urban neighborhoods and serving a spatially limited, densely populated delivery area. Katsela et al. (2022) see their main advantage in consolidating transport and enabling a shift to sustainable electric and non-motorized modes of transport, such as electric cargo bikes or hand trucks. According to Kim and Bhatt (2019), a delivery micro hub can take the form of a building or a mobile structure and can be operated permanently or temporarily, by one or more companies simultaneously. They also describe three distinct applications of micro hubs. These include an independent micro hub operated by a company on its own, a shared micro hub utilized by multiple companies, and a consolidated micro hub where one company centralizes all deliveries for multiple companies using its micro hub. Several researchers have discussed the advantages of micro hub applications for the last mile delivery. For instance, Janjevic and Ndiaye (2017) and Björklund and Johansson (2018) present how cost efficiency can be achieved by emphasizing, e.g., the role of intercompany cooperation leading to an increasing and consolidated volume of distributed cargo. Taking into consideration environmental aspects, Ouhader and El Kyal (2017) investigate the potential economic and environmental effects of combining depot location and vehicle routing to decrease CO_2 emissions through a horizontal collaboration. Finally, social benefits coming from the micro hub applications represent, e.g., an easing of traffic congestion and a reduction of noise pollution in densely populated areas (Kiba-Janiak et al., 2021).

The optimal location of a micro hub represents a crucial decision in urban logistics planning. Several factors need to be considered to determine the best location for a micro hub, including proximity to the delivery area, accessibility, demand patterns, and operational efficiency. One approach to determining the optimal location of a micro hub is through the use of mathematical models and optimization techniques. These models consider factors such as demand density, transportation costs, and service coverage to identify the most suitable location (Shahparvari et al., 2020). Techniques such as the p-median problem, facility location problem, and location-allocation models are commonly used in this context (Muñuzuri et al., 2012). Geographic information system (GIS) tools and spatial analysis techniques can also be employed to evaluate potential locations for micro hubs. GIS allows for the integration of various spatial data, such as population density, road networks, and existing infrastructure, to identify areas that are well-suited for micro-hub placement (Cheng & Pan, 2021). By analyzing these spatial factors, decision-makers can identify locations that minimize travel distances, reduce congestion, and optimize delivery routes. Furthermore, simulation and modeling techniques can be utilized to assess the impact of different micro hub locations on operational performance and cost-effectiveness. Simulation models can simulate the movement of goods, vehicles, and personnel within the urban area to evaluate the efficiency and effectiveness of different micro-hub locations (Llorca & Moeckel, 2021).

These models can consider factors such as delivery time, vehicle utilization, and resource allocation to identify the most efficient location. Collaboration and stakeholder engagement are also important in determining the optimal location of micro hubs. Involving key stakeholders, such as logistics service providers, local authorities, and community representatives, can provide valuable insights into the specific needs and characteristics of the urban area (Robichet et al., 2022). Collaborative efforts can lead to the identification of locations that align with the goals and requirements of all stakeholders involved.

2. Research methodology

To obtain a default knowledge about the location of the single micro hub, we use a basic mathematical description of the facility location problem described for example in Farahani et al. (2014):

$$\min z = \sum_{i=1}^{n} \sqrt{(x - x_j)^2 + (y - y_j)^2} \cdot q_j \quad (1)$$

where: x – longitude of the micro hub; y – latitude of the micro hub; x_j – longitude of a j^{th} B2B customer operating in Prague 1, 2 or 3; y_j – latitude of a j^{th} B2B customer operating in Prague 1, 2 or 3; n – total number of B2B customers operating in Prague 1, 2 or 3; q_j – quantity demanded in a certain period by a j^{th} B2B customer operating in Prague 1, 2 or 3.

In the contemporary distribution system, all B2B customers operating in Prague 1, 2, and 3 are served by the 3PL partner from a leased regional terminal located on southwestern edge of Prague (Fig. 1).

Fig. 1: Contemporary parcel distribution system

Source: own (based on Pánek et al. (2021))

The collection and the distribution of consignments in the current distribution system are executed mostly with the help of 12 tons vehicles using combustion engines. To ensure full utilization of logistic capacities customers located in the Prague region are served together with the customers operating in the Central Bohemian Region.

To obtain input data for Equation (1) we analyze customer orders for Prague and Central Bohemian Region covering 1 year period using MS Excel. For each order, a quantity to be transported and a delivery/pick up address is specified including a street name, a land/registry number, and a postal code. Based on a postal code we separate orders placed to a pipeline by the customers located in Prague 1, 2, and 3. Then, for each separated order we use string variables *"Street"&", "&"Land Registry Number/ House Number"&", "&" Postal code"* as an input to the custom function described in Dyntar et al. (2020). This function returns latitudes and longitudes as a result of Google Maps queries. We plot all obtained locations on the graph and remove possible outliers. We use the GRG non-linear method in Solver add-in to minimize the target function in Equation (1) and obtain coordinates of the micro hub. We connect the original micro hub location with the regional terminal to specify a promising direction for a micro hub location adjustment. In the neighborhood of this connection outside Prague 1, 2, 3 area we search for suitable B2B customers as well as for other 3PLs already operating logistic facilities in this neighborhood to check their willingness to cooperate and share their logistic capacities. We use the CZ-NACE classification, to check core business of each potentially suitable B2B customer focusing primarily on partners from the field of manufacturing because we expect these partners to cooperate more willingly than for example retailers or providers of services in accommodation. Moreover, we also assess the suitability of B2B customers for cooperation based on total demanded quantity in 1 year period and their distance from the original location of the micro hub. We approach potentially suitable partners with an offer to negotiate about cooperation. Then, for the partners potentially interested in cooperation we simulate 1 month of micro hub operation as if it is located at the place of business of this partner. We use balancing to calculate the required area of the micro hub and also VRP open solver add-in (Erdogan, 2017) to solve capacitated vehicle routing problem taking place during the collection and distribution of parcels in Prague 1, 2, and 3. We assume a cargo bike to collect/distribute shipments weighing up to 200 kg and an electric van for shipments up to 1.5 tons. We further assume an average handling of parcels to last 5 minutes/visit at customers and 10 minutes/visit in the micro hub.

3. Results and discussion

3.1 Results

Fig. 2 shows the location of the micro hub within 240 B2B customers operating in Prague 1, 2, and 3.

The coordinates of the micro hub are 14.4312623094322; 50.0867101205772 referring to the Hybernska/Dlážděná street in Prague 1. It is obvious that locating the micro hub in this part of Prague is not allowed and that the position must be therefore adjusted.

The connection between the original micro hub location and the location of the related regional terminal shows that promising alternative hub locations can appear most likely in Prague 5, worse option represents its placement in Prague 13 or 17 (Fig. 1 and Fig. 3).

Based on the analysis of orders during 1 year period, we identify 178 B2B customers in Prague 5, 13, and 17 (i.e., potential vertical partners). These can be seen in Fig. 3. Fig. 3 also shows other 3PLs running 9 logistic facilities in this area (i.e., potential horizontal partners).

Based on the analysis of orders during 1 year period, we also calculate total demand percentiles for each potential vertical partner (Tab. 1).

Using the 80% percentile of total demand we reduce the number of potential vertical partners to those who demand the transport of at least 39 m^3 per year. After the further limitation of a number of potential vertical partners according to their core business, we offer the cooperation to 13 potential vertical partners, of which 9 refuse and 4 express interest. Similarly, we offer cooperation to 4 potential horizontal partners according to the distance of their logistic facilities from the original micro hub location, of which 3 refuse and 1 shows interest. The locations of both interested and not interested potential partners are shown in Fig. 4.

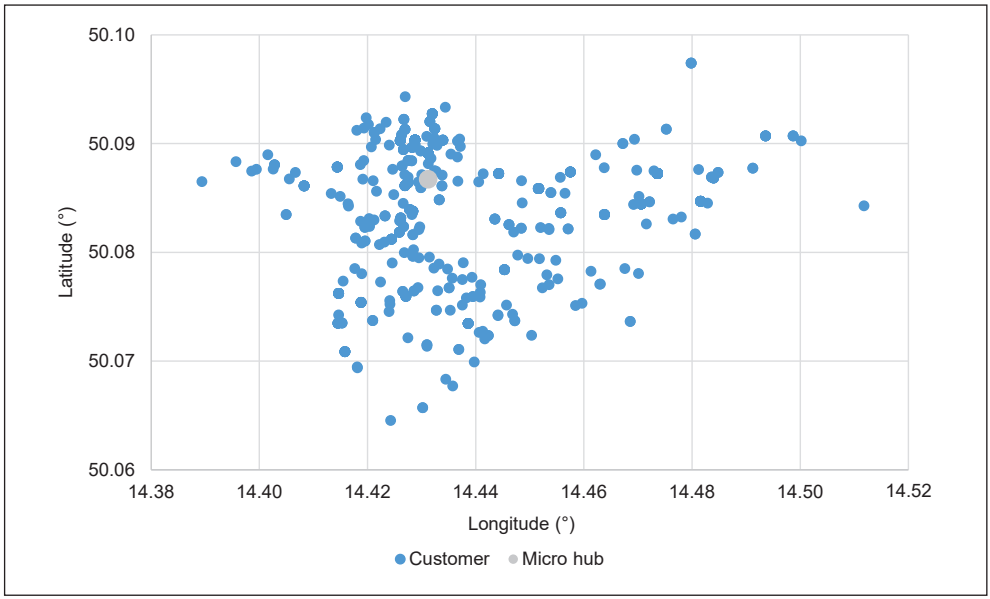

Fig. 2: **Micro hub location based on the solution of facility location problem**

Source: own

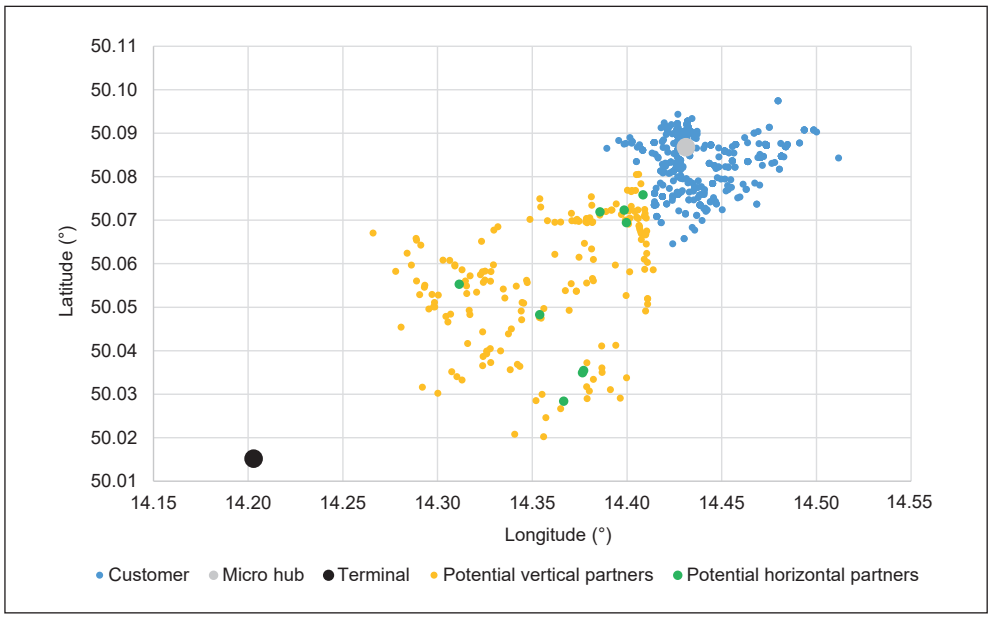

Fig. 3: **Adjustment of micro hub location – potential vertical and horizontal partners**

Source: own

Tab. 1: **One year total demand of each potential vertical partner - percentiles**

	Percentile										
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Demand (m^3)	0	0	3	5	8	12	16	23	39	69	481

Source: own

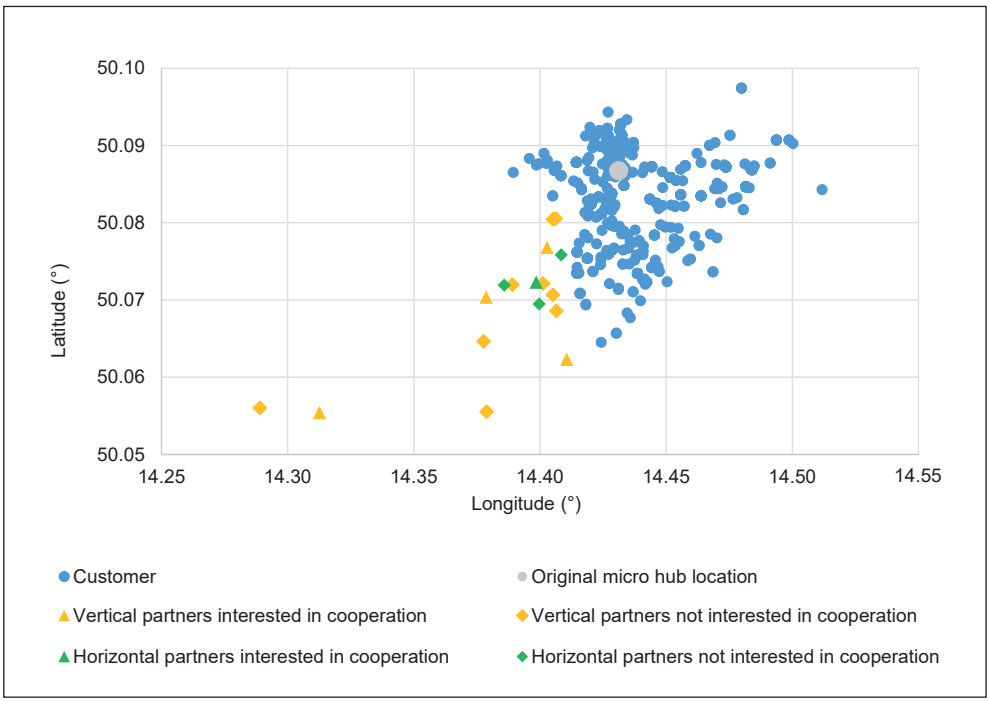

Fig. 4: **Adjustment of micro hub location – partners (not)interested in cooperation**

Source: own

Fig. 5 shows required space of micro hub coming from balancing.

The required space is calculated as a daily collected cargo plus a cargo to be distributed next day describing the worst case of a regular transport line commuting between regional terminal and the micro hub passing by vehicles responsible for collecting and distributing cargo within Prague 1, 2, 3. Assuming an average height of transported units to be 0.5 meters the required area of the micro hub based on the balancing 1 month period averages 64 m^2 with a maximum 125 m^2.

Another very important output for negotiation about cooperation with both types of partners represents the required number of vehicles and their utilization during the collecting and distribution process. These outputs coming from the VRP solver add-in can be seen in Fig. 6, Fig. 7, and Tab. 2 for the micro hub located near Anděl, Prague 5 in the facility of the horizontal partner interested in cooperation.

It can be seen in Tab. 2 that the 50% percentile for 8 hours/day FTEs means to employ 1 cargo bike utilized up to 71% and

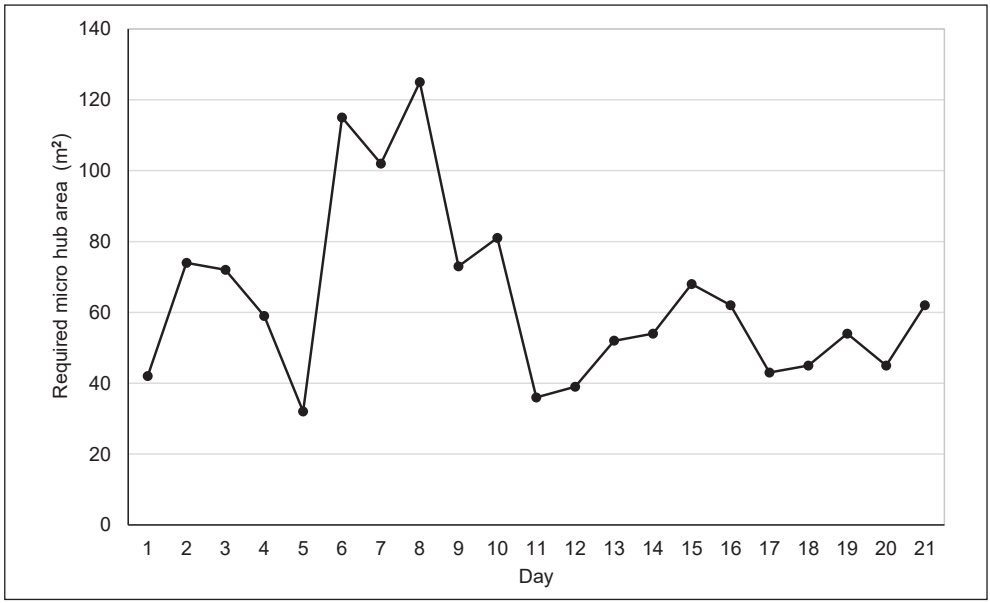

Fig. 5: **Required micro hub area**

Source: own

Fig. 6: **Simulation of micro hub operation – time utilization of cargo bikes**

Source: own

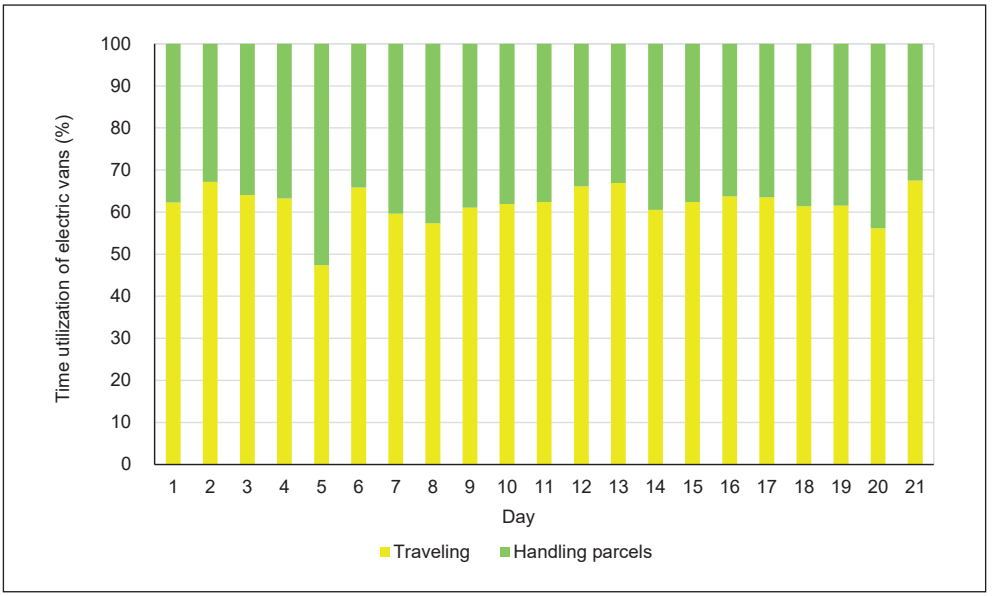

Fig. 7: **Simulation of micro hub operation – time utilization of electric vans**

Source: own

Tab. 2: **Number of visits of micro hub and full-time equivalents (FTEs)**

	Percentile										
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Cargo bike (FTEs)	0.43	0.51	0.58	0.59	0.66	0.71	0.79	0.82	0.83	0.94	1.51
Cargo bike micro hub visits	4	4	5	6	6	7	7	8	8	10	16
Electric van (FTEs)	0.08	0.24	0.46	0.47	0.49	0.53	0.57	0.66	0.90	1.09	1.25
Electric van micro hub visits	1	2	4	4	5	5	5	6	8	9	13

Source: own

1 electric van utilized up to 53% with a maximum of 1.51 FTEs for cargo bikes and 1.25 for electric vans. From the operational point of view as well as for residents living in the neighborhood of potentially shared facility it is also important to know the number of visits of vehicles as the density of transportation can highly increase in this area. Outputs in Tab. 2 show that 50% percentile means up to 7 visits of cargo bikes and up to 5 visits of electric vans per day with a maximum of 16 visits of cargo bikes and 13 visits of electric vans per day. Mainly for horizontal partners, it is also important to know about the time utilization of vehicles as these can be also shared while traveling from/to customers. It can be seen that the daily traveling time of cargo bikes is relatively stable ranging from 53% to 62%. For electric vans, it fluctuates more significantly between 47% and 67%. Furthermore, the average utilization of load capacity is 84% for cargo bikes and 71% for electric vans which, especially in the case of electric vans, offers the potential to increase the utilization of load capacity through sharing.

3.2 Discussion

While the outputs in Fig. 4 represent information on which supply chain partners are interested in starting negotiations on the terms of cooperation (i.e., locating the micro hub in their facilities), the outputs in Figs. 5–7 and Tab. 2 imply economic consequences of adopting such innovative sustainable supply chain solution and can also serve to motivate these partners differently.

For both, vertical and horizontal partners direct economic benefits are coming from the sharing space in the logistic facilities. This is consistent for example with the research by Luo et al. (2021) highlighting that shared space in logistics facilities can lead to cost savings through the efficient utilization of resources and infrastructure. Moreover, the sharing of physical assets, production factors, and strategic alliances among existing facilities and value-added services in logistics clusters has been found to improve the efficiency of global supply chains and reduce costs (He et al., 2018). Together with sharing the space, there is also a potential mainly for horizontal partners to share the capacities of vehicles and reach economic (Deng et al., 2020) and environmental benefits (Grote et al., 2021) as well as to exchange knowledge and experience about the joint core business and increase its overall efficiency (Jazairy et al., 2017). We further see the opportunity for vertical partners to get for example priority handling of their shipments during the distribution across the board in exchange for space in their facilities and gain competitive advantage through order lead time reduction.

There are also several strategic reasons for cooperation having a potentially tremendous impact on urban area business in the future. Voluntary involvement in cooperation that reduces the negative effects of distribution logistics builds the image of a responsible organization and can for example prevent municipalities from tightening the rules or expanding the area in which the rules are applied due to increasing pressure from residents. This corresponds to the motivation of business partners to participate in the execution of backflows in closed-loop supply chains (Kazancoglu et al., 2021). Sharing space in logistic facilities helps to maintain business in the limited number of traditional localities where residents show a certain tolerance because of the historical experience. This is similar to the behavior of residents in a situation of building/extending a nuclear power station on a new/existing site (Zhu et al., 2016). Sharing of vehicles leads to the reduction of traffic congestion, exhaust gas emissions, and sound pollution levels. It also limits the need for additional parking space to a certain extent. This kind of action contributes to maintaining the trade-off between the possibility of serving legislatively restricted areas from a relatively acceptable distance and the full life of people in the city center until the electrification of transport advances enough to be economically meaningful for this kind of business application.

Conclusions

In this paper we describe a micro hub location in the neighborhood of the historic center of the city of Prague, the Czech Republic in the situation when the municipalities consider prohibiting the entry of trucks with a combustion engine that currently provides cargo transportation for B2B partners operating in this area. Micro hubs represent the efficient last mile consolidation and distribution facilities located in or near urban neighborhoods and serving a spatially limited, densely populated delivery area. We propose a solution combining facility location problem, vehicle routing problem and balancing with the horizontal and vertical cooperation in supply chains to locate the micro hub in the area with extremely low availability of suitable space while respecting the necessity to connect this facility to an existing network of regional terminals operated by 3PLs to ensure the distribution of cargo across the board according to the requirements of customers. For pickup and delivery of parcels within the area, we suggest using cargo bikes and electric vans to provide environmentally sustainable service and minimize the harmful consequences of excessive traffic for residents. We also discuss the economic implications of adopting such innovative sustainable supply chain solutions for involved horizontal and vertical supply chain partners emphasizing different motivation aspects to convince these partners to cooperate and share scarce resources. We believe that our solution examining the facility location problem rather from a management point of view than a sole operations research problem leads to interesting results in situations when local conditions are quite specific and are therefore of interest to both researchers and practitioners.

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Information and communication technology diffusion, supply chain performance, health care and human development: A case of the South Asian region

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Abstract: *South Asian countries have shown tremendous progress in information and communication technology (ICT) and have become one of the fastest-growing regions in technology, innovation, and business competitiveness. The pivotal role of ICT diffusion in the economic growth of both developed and developing countries is a well-established fact. Therefore, this research aims to examine the impact of ICT diffusion (especially the evaluation of ICT indicators) on three core outcomes, namely supply chain performance, health-care expenditures, and the Human Development Index in the context of South Asian economies. To measure ICT, we used three core ICT indicators (i.e., fixed broadband subscriptions, mobile phone subscribers, and internet users) individually as well as in the form of an index developed through principal component analysis (PCA). Panel data of South Asian economies ranging from 2007 to 2021 were used to estimate the equations. The outcomes revealed that all the variables were integrated at order one (1). Second, ICT had a long-run/equilibrium relationship with supply chain performance, health-care expenditures, and human development index. Third, the response of all individual ICT indicators as well as the ICT index on supply chain performance was positive and significant in estimated coefficients. Fourth, the ICT index and all ICT indicators had a positive influence on health-care expenditures. Finally, the ICT index and two out of three individual ICT indicators had a positive and significant influence on HDI. Interestingly, among all the three indicators of ICT, internet users were found to have more pronounced effects on the promotion of supply chain performance, health-care expenditure, and HDI. The more pronounced effect of internet users implied that policymakers should consider devising policies to promote ICT penetration with a core focus on internet penetration.*

Keywords: *ICT diffusion, supply chain, health-care expenditures, human development, principal component analysis (PCA), South Asia.*

JEL Classification: *L86, H51, H75, C22.*

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Introduction

Information and communication technology (ICT) has experienced unprecedented development over the last few decades (Hussain, 2021; Wallengren et al., 2023). Today, ICT is indispensable to almost every field of human life. These fields range from energy consumption, better development processes, health-care services, education, and quality of life to the economic improvement of nations. However, people's criteria for well-being differ depending on their level of societal development (Otoo & Nemati, 2017). For instance, individuals in developed countries believe that higher-order needs (i.e., self-actualisation, social, and esteem) are much more important for their well-being, whereas in developing countries, lower-order needs (i.e., safety and biology-related) are considered more imperative (Sirgy, 1986). Similarly, ICT and its components (access to the internet, landline connections, and cell phone users) have differential effects on developed and developing economies of the world (Stanley, 2018). As per ITU-2019, ICT diffusion (i.e., mobile phone subscription and internet usage services) has substantially increased in the developing and least developing economies over the period 2005–2019. Fig. 1 reflects that in all South Asian economies, mobile phone subscribers per 100 inhabitants have substantially increased during the whole sample period, especially from 2008 onwards. Fig. 1 highlights that since 2015, every South Asian economy, even with its developing nature, still had more than 60 mobile subscribers out of 100 people (Fig. 1). Further, Fig. 2 shows the internet users growth in South Asian economies and confirms the remarkable growth of internet diffusion in all selected economies during the whole sample period (Fig. 2). Therefore, in developing countries, it is more pertinent to focus on lower-order needs such as operational efficiency, health-care expenditures, years of schooling, and life expectancy.

ICT plays a critical role in modern supply chain management by enhancing efficiency, collaboration, and decision-making across various stages of the supply chain (Kitheka, 2012). ICT tools allow real-time collaboration between different organisations in the supply chain field, whereas cloud-based platforms and communication tools streamline information sharing and coordination, leading to faster response times and reduced miscommunication. Similarly, Liu et al. (2023) documented that investing in research and development (R&D) enhances the efficiency of enterprise innovation processes. Likewise, ICT also facilitates the use of optimisation algorithms to determine the most efficient production schedules, transportation routes, and appropriate vehicle sizes for each order. This not only reduces transportation costs, but also improves delivery times and minimises the carbon footprint (Asghari & Al-E-Hashem, 2021).

The focus on health-care expenditures has been increasing, especially since the recent COVID-19 outbreak. Nonetheless, the fragility of the health-care system in lower-middle-income economies, such as India, Pakistan, Bangladesh, Sri Lanka, Bhutan, and Nepal, has also been exposed during this pandemic. Furthermore, according to the World Health Organization (WHO) 2021 report, these South Asian countries have a health expenditure-to-gross domestic product (GDP) ratio of 3.10%, and per capita health expenditures are as low as USD 60.58, which are far below the global average values of 9.84% and USD 1,121.8, respectively. These statistics reveal that there is substantial room for South Asian countries to invest in their health-care systems and provide better health facilities to the public. However, scarce financial resources, rural populations, and dilapidated health-care infrastructure are barriers to providing the necessary health services. These factors have contributed to the emergence of innovative and smart technologies in the health-care sectors of many developing countries. The growing popularity and usage of ICT are helping to change the delivery of face-to-face health-care facilities to many online platforms. Electronic health (e-health) has

become one of the most popular applications of ICT in developing countries, aiding health-care systems through telemedicine, electronic health records, telehealth, and health-care information systems (Omotosho et al., 2019). Moreover, ICT diffusion has helped lower-income countries provide their residents with access to state-of-the-art health-care facilities without making large investments in fixed-line technologies (Bastawrous & Armstrong, 2013).

The human development index (HDI) is a composite index of life expectancy, education and per capita income of a country. More precisely, the HDI comprises a reasonable standard of living (gross national income; GNI per capita), knowledge (education), and a long and healthy life (life expectancy) of citizens (Akbar et al., 2020). The current era is also known as the information age, which is a phase of rapidly growing digital knowledge that provides access to and administers information. In this context, a plethora of studies consider ICT's growing diffusion as a key factor in human capital development (Asongu & Tchamyou, 2019). In addition, the eminent role of ICT in improving economic growth and human well-being is discussed in international forums such as the World Economic Forum (WEF; Gupta et al., 2019).

In light of these arguments, it is reasonable to posit that ICT diffusion has the potential to affect supply chain performance, health-care expenditure, and HDI in developing South Asian economies. However, several studies have found that ICT diffusion in the health-care sector does not yield significant outcomes (Free et al., 2013; Shahzad et al., 2020). By contrast, Omotosho et al. (2019) contended that ICT has contributed significantly to the health-care sector in different countries. Furthermore, scholars are doubtful about the long-term success of ICT in health-care (Lucas, 2008). Similarly, the nexus between ICT and HDI also produces contradictory findings across countries (Karaman Aksentijević et al., 2021).

One possible explanation for these contrasting findings could be that these studies were conducted in different regions of the world with varying levels of economic and social development. However, as postulated by Maslow's hierarchy of needs theory, residents of developed (self-actualisation and esteem) and developing (security and safety) countries have dissimilar preferences (Abbas, 2020; Numonjonovich, 2022). This study examined the role of ICT in boosting supply chain management (SCM) performance, health-care, and human

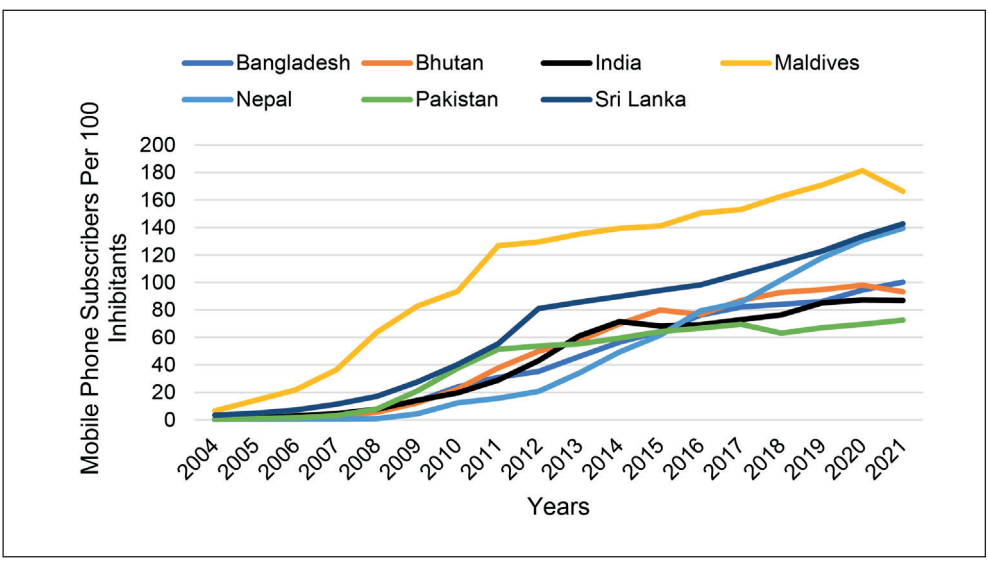

Fig. 1: South Asian mobile phone diffusion experience

Source: own (based on World Bank Data)

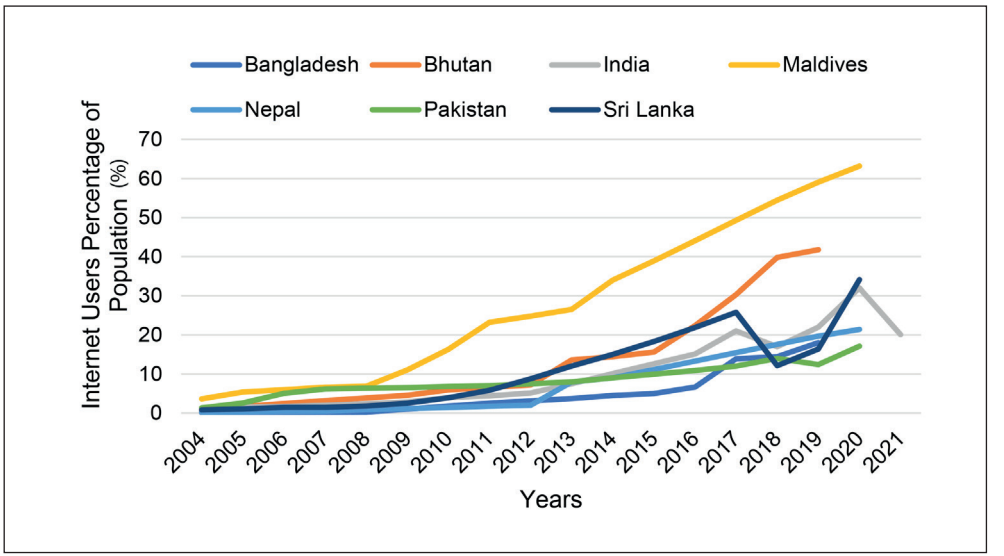

Fig. 2: South Asian internet adoption experience

Source: own (based on World Bank Data)

development in the context of developing South Asian economies.

For this purpose, we employed three different ICT indicators (i.e., fixed broadband subscriptions, mobile phone subscribers, and internet users) individually as well as in the form of a composite index developed through PCA to link supply chain performance, health-care, and HDI by using a sample of balanced panels spanning from 2007 to 2021.

This study contributes to existing literature in several ways. First, it extends the theoretical and empirical literature on ICT indicators, SCM performance, health-care expenditures, HDI, and developing economies. Second, to the best of our knowledge, this is the first comprehensive study that uses three different ICT indicators (i.e., fixed broadband subscriptions, mobile phone subscribers, and internet users) individually, as well as in the form of a composite index, to inspect the diffusion of ICT in the promotion of SCM performance in health-care and human development. Furthermore, the current study aims to provide evidence regarding the dynamic nature of SCM performance, health-care, and human development and their linkages with ICT diffusion, especially in the case of developing economies, reflecting that the current research introduces fundamentally distinct and economically vital information. Fourth, the current study contributes to the existing literature by evaluating whether the effect of ICT diffusion on SCM performance, health-care, and human development is long-term in developing economies. Fifth, an existing strand of literature usually uses cross-sectional (one-year) data to examine the role of ICT diffusion on developments; however, this study used a 15-year data set spanning from 2007 to 2021, and this period was considered based on when ICT developments were rapidly taking place, especially in low-income countries (i.e., South Asia). Finally, this study is unique because it was conducted in a South Asian economy.

The choice of a South Asian economy can be justified in several ways. First, South Asian countries are developing economies with dense populations; the region is home to almost one-fourth of the world's population. Second, most South Asian countries are in the developing phase, in which rapid growth in the ICT sector has been observed (Figs.1–2). Third, selected South Asian countries are heedful of competitiveness through the deployment of ICT and are becoming the fastest-growing regions in

the context of technology and innovation (World Economic Forum, 2016). Finally, it is pertinent to explore the association between ICT, HDI, and health expenditures to attain millennium development goals, especially in the context of populated emerging economies such as South Asia.

The remainder of this paper is structured as follows: the 1st section evaluates the literature review to formulate the hypothesis and theoretical underpinnings; the 2nd section covers data selection, operational definitions of variables, and methodological approaches; the 3rd section consists of empirical outcomes and their discussions; and the last section concludes the research and provides practical implications.

1. Literature and theoretical underpinnings

1.1 Theoretical background

The digital technology-health relationship can be characterised by four primary theories: i) the use and gratification theory; ii) the technology acceptance theory; iii) the displacement theory; and iv) the health behavior change theory and health belief model.

Use and gratification theory

The use and gratification theory, originating from the literature on communication and media effects, was formulated to understand the motives behind technology utilisation (Katz et al., 1973; Whiting & Williams, 2013). This theory posits that individuals engage with the internet and media to meet their needs, anticipating rewards and gratification. In this context, the theory offers insights into why platforms such as the internet, social media, and ICTs are employed to address health-related concerns. Whiting and Williams (2013) proposed various gratification factors, including social interaction, information seeking and sharing, expression of opinions, and interpersonal communication, as justifications for the use of social media. Further, the literature asserts that both the internet and social media serve as avenues for individuals to access and disseminate health-related information (Jiang & Street, 2017; Koch-Weser et al., 2010).

Technology acceptance theory

Among ICT theories, the technology acceptance model (TAM) is the most widely accepted model for demonstrating consumers' acceptance of technology and the impact of technology acceptance on human life (Kabir et al., 2022). The TAM has recently been adopted to analyse numerous elements that influence consumer behaviour in the areas of human development and health information technology (Adeola & Evans, 2018; Wong et al., 2018). The TAM has been constantly enlarged, with each expansion spurred by the need to forecast the adoption of new information technology (IT) (Granić & Marangunić, 2019; Thompson & Brailer, 2004). By using cultural trends and the social environment as the primary variables, the TAM focuses on the characteristics of a given technology that influence consumers acceptance of the technology. As a result, TAM is a valuable model for developing strategies to promote the acceptance of information technology, as it establishes a direct relationship between acceptance of the technology and its perceived usability (Rana et al., 2020). Many studies have adapted the TAM to study health information systems and human developmental processes (Adeola & Evans, 2018; Wong et al., 2018). Thompson and Brailer (2004) demonstrated that the extended application of the TAM in health information systems is compelling for the valid description of consumer behaviour intentions. Similarly, Dünnebeil et al. (2012) revealed that the perceived importance of IT utilisation was among the most crucial motivators for accepting electronic health-care. The TAM is effective for predicting physicians intentions to use teledermatology, with the perception that facilitators use technologies (e.g., training, infrastructure, and support) being the most important variable (Orruño et al., 2011). These findings imply that the TAM can be effectively integrated with other theoretical frameworks to better explain health-care expenditures and digital health acceptability.

Displacement theory

Unlike the first two theories, which highlight the positive impacts of technology, the displacement theory underscores the adverse consequences of frequent and excessive technology usage. Unrestricted reliance on technology has been linked to various health issues, such as headaches, back pain, sleep disturbances, and obesity (Brindova et al., 2015; Vandewater et al., 2004). One plausible explanation for these negative effects is that time spent online could otherwise be allocated to alternative

activities, including physical pursuits and sports, which are notably absent in cases of prolonged and excessive technology use (Brindova et al., 2015).

Health and behavioral change theory and health belief model

The health behaviour change theory posits that technology serves as a catalyst for transitioning from inappropriate and risky health behaviours to more suitable and recommended ones. In this context, digital technologies have become valuable tools for health professionals to assist individuals in optimising, maintaining, and enhancing their health behaviours and overall well-being (Ahadzadeh et al., 2015). The health belief model is a prominent model used to elucidate the role of technology in health behavioural changes. As outlined by Kim and Park (2012), this model proposes that individuals are more inclined to adopt specific health-related behaviours when, beyond recognising a personal threat, they are persuaded of the efficacy of positive behavioural changes. This line of reasoning can be extrapolated to the realm of the technology-health relationship, where individuals are likely to modify their behaviour if they perceive a risk to their health (perceived health risk) and concurrently recognise the tangible health benefits associated with technology use (health consciousness), as described by Deshpande et al. (2009) and Naslund et al. (2017).

1.2 Empirical literature on ICT and supply chain performance

The integration of ICT tools and systems into supply chain processes has emerged as a significant driver of enhanced operational performance. The internet of things (IoT), machine learning, and big data analytics help analyse the large volumes of data generated in the supply chain (Mishra & Tyagi, 2022; Queiroz et al., 2021; Spieske & Birkel, 2021). This data-driven approach enables policymakers to identify trends and potential issues, leading to better decision-making and improved supply chain efficiency. Furthermore, ICT enables organisations to forecast demand, track inventory, and plan replacements accurately. This reduces excess inventory, minimises holding costs, and ensures that products are available when needed, without inventory pile-ups (Samuel, 2012). ICT systems also assist in analysing customer demand signals, allowing organisations to adjust production and distribution plans based on changing customer preferences and market trends. ICT solutions also provide real-time data on potential disruptions, such as natural disasters, geopolitical events, and supply chain disruptions (Sako, 2022). This allows policymakers to proactively assess risks and develop alternative plans to ensure supply chain resilience.

Researchers have consistently documented the positive impact of technology integration on various supply chain dimensions. Su and Yang (2010) found that the adoption of advanced information systems, such as Enterprise Resource Planning (ERP) systems, facilitates real-time information sharing, leading to reduced lead times and increased responsiveness to market demand. Similarly, Li and Visich (2006) noted that the integration of Radio Frequency Identification (RFID) technology improved inventory accuracy and visibility, resulting in reduced stock outs and improved customer satisfaction. Information sharing and collaboration are key components of effective supply chain management, and ICT plays a pivotal role in enabling seamless communication between supply chain partners (Huong Tran et al., 2016). Technologies such as electronic data interchange and Radio Frequency Identification (RFID) have been shown to improve information visibility and coordination. These technologies also facilitate real-time data exchange, support better decision-making, and reduce information asymmetry among partners. Consequently, operational efficiency increases substantially (Varma & Khan, 2014). Supply chain visibility and responsiveness have been boosted by ICT tools such as sensors and IoT devices. The ability to track goods, monitor inventory levels, and predict demand fluctuations in real time has proven valuable for optimising supply chain performance (Dehning et al., 2007). Enhanced visibility empowers organisations to respond promptly to disruptions, minimise stock-outs, and optimise inventory levels (Patil et al., 2023).

E-commerce platforms and online procurement systems have introduced novel dimensions to supply chain operations. Research indicates that e-commerce integration has enabled improved supplier competition, cost savings through reduced transaction expenses, and greater order processing accuracy (Chandrasekar

Subramaniam, 2002). Furthermore, e-commerce platforms serve as interfaces for direct communication between buyers and suppliers, fostering efficient collaboration and customisation (Helms et al., 2008; Schubert & Ginsburg, 2000). However, adopting ICT in supply chains is challenging. Organisations often encounter barriers, such as data security concerns, compatibility issues, and resistance to change (Ghobakhloo et al., 2012; Henderson & Ruikar, 2010). Effective implementation of ICT solutions requires addressing these challenges and fostering a culture of technological acceptance. Similarly, another study argued that organisations should actively work towards the integration of ICT into their supply chains to decrease delivery cycles and enhance supply chain flexibility, ultimately aiming for superior performance (Zhu et al., 2022). Therefore, companies should innovatively employ ICT resources and implement appropriate ICT alignment strategies to achieve elevated levels of performance within their supply chains.

In summary, the empirical literature on the significant role of ICT in shaping modern supply chain practices overly focuses on the integration of ICT to enhance operational efficiency, information sharing, visibility, and collaboration while struggling to overcome the threats of data security and compatibility. As technology continues to evolve, understanding the interplay between ICT adoption and overall supply chain performance remains essential, but unexplored, especially in the context of developing regions such as South Asia. Drawing on the aforementioned arguments, this study proposes a hypothesis concerning the correlation between ICT and supply chain performance.

H1: ICT has a *significant impact on supply chain performance.*

1.3 Empirical literature on ICT and health-care expenditures

ICT is one of the crucial front-stage performing factors affecting human life. In particular, for developing economies, infiltration can expedite development (Hussain et al., 2021). Several studies have investigated the impact of ICT on human life (Alhassan & Adam, 2021; Asare, 2020; Evans, 2018; Lee et al., 2021). To explain the significance of ICT in the health-care department, Omotosho et al. (2019) argued that, with the widespread availability of affordable, high-quality health-care and its widespread adoption, electronic health is a well-liked application of ICT. Further, Evans (2018) contends that ICT is positively associated with financial inclusion in the shape of the internet and mobile phones. A panel data analysis of 44 African countries from 2000 to 2016 revealed that ICT implications cause financial inclusion, which may lead to better health-care spending. Badran (2019) states that ICT is used in health products, services, and procedures, along with organisational transformation in health-care systems, new skills, and electronic health. It increases the economic and social worth of health, the health of citizens, and the effectiveness and productivity of health-care services. The growing availability of ICT for various businesses provides higher efficiencies, and the health-care industry is no different, with EHC (electronic health-care) being a sort of ICT application within e-health. This implies that ICT is closely situated in the health-care department, particularly in determining health-care expenditures. Omotosho et al. (2019) examined the ongoing state of ICT in health-care delivery in developing economies using a sample of African countries and found that electronic health is among the most well-liked application of ICT. It has significantly improved health-care provisions by offering high-quality medical treatment and widespread accessibility at lower costs. Although this type of health service is becoming more popular in developing countries, these countries face obstacles when it comes to creating and setting up electronic health services on both local and large scales. Thompson and Brailer (2004) emphasise the importance of ICT in health departments and state that a new vision of health-care is possible with the help of ICT. They concluded that there was a strong relationship between ICT and health-care expenditures.

Dutta et al. (2019) assert that ICT can enhance health-care services by closing the information divide between health-care providers and beneficiaries. Recognising the significant impact of ICT on health outcomes, policymakers in Asian nations should incorporate ICT into existing programs and systems. Nevertheless, the effective integration of ICT relies on the participation of beneficiaries and end users. Therefore, policymakers must conduct stakeholder analyses to foster stakeholder involvement from the initial stages through the ultimate utilisation of suitable technology. Furthermore, Nevado

et al. (2019) argued that digital citizens are far more happy living in regions with technological capabilities and are concerned with achieving sustainable growth. Another study confirmed that the diffusion of ICT enhances health outcomes by influencing the augmentation of public health-care expenditure at the macro level and fostering individual health literacy at the micro level (Zhang, 2022). On the other hand, Shahzad et al. (2020) explored the dynamic linkage between ICT and health expenditures. They stated that ICT has a negative impact on health-care expenditure. Similarly, another concurrent study reported a negative association between ICT and health-care expenditures in Saudi Arabia (Akeel, 2022). Adeola and Evans (2018) examined the association between ICT and health in Africa from 1995 to 2015. Panel generalised method of moments (GMM) and Toda-Yamamoto causality tests were used to test this relationship. The empirical findings indicated that ICT has a positive and significant association with health, with higher levels of ICT indicating better health. The findingd reported a bidirectional causation between the two. Ariani et al. (2017) argued that there is an increasing demand for a reliable, trustworthy, and effective health-care delivery system worldwide, particularly in developing countries with large populations and remote, difficult-to-reach locations. The use of ICT in the delivery of health-care services, particularly e-health and its subcategory mobile health (m-health), has a huge potential to cut costs, promote health information interchange, and improve patient outcomes. Furthermore, ICT diffusion improves health outcomes by increasing spending on health-care facilities (Zhang et al., 2022). Based on these arguments, this study posited a correlation between ICT and health-care expenditures.

H2: ICT has a *significant impact on health-care expenditures.*

1.4 Empirical literature on ICT and human development index

Quality of life is an important factor in the long-term growth of countries, regions, and cities. However, because of the difficulty of measuring this, there are no clear criteria for which economic components should be measured to improve living circumstances. The HDI is a measure of a country's level of human development in several categories, such as health, life expectancy, and education (Hopkins, 1991). The HDI ranks countries into four categories based on three measures: education, life expectancy, and living standards (Khan et al., 2018).

ICT significantly influences the HDI through various channels. Access to information and education, economic opportunities, improved health-care, enhanced communication, social inclusion, innovation, and effective data management are key ways in which ICT contributes to human development. However, the impact varies based on factors such as infrastructure, digital literacy, and inclusivity in ICT policies. Balancing these considerations is essential for ensuring ethical and inclusive development. The HDI level varies from country to country, resulting in disparities in productivity between countries' ICT and innovation in Colombia's MIPYMES. An astronomical wave of research has explored the components of HDI and their relationship with ICT (Machfud & Kartiwi, 2018; Zhang, 2019). To explain how ICT and HDI are interlinked, Zhang (2019) explored their relationship. A sample of developing Asian countries from 1990 to 2016 documented that better HDI is related to better ICT facilities. Ejemeyovwi et al. (2018) determined the impact of ICT investment on the HDI. Among other things, this study reveals that investment in ICT has no statistically meaningful association with human development. The factors responsible for the insignificant influence of telecommunications investment on human development could be linked to relatively low telecommunications investment combined with high technology acquisition costs. Another study affirmed that ICT penetration (i.e., mobile phone penetration and internet penetration simultaneously) affects human development consistently in middle-upper-income countries (Adegboye et al., 2022).

Another study by Nevado et al. (2019) found a clear association between ICT use and quality of life. Moreover, they argued that digital citizens are happy with their technological capacities. Machfud and Kartiwi (2018) examined the relationship between ICT and HDI. An examination of six major islands in Indonesia from 2012 to 2016 revealed a connection between ICT and HDI. In general, the better the ICT development, the greater a region's human development; conversely, the lower the ICT development, the worse the poverty level. This study also revealed inequalities in human and ICT development across Indonesia's

western and eastern regions. Moreover, Kowal and Paliwoda-Pękosz (2017) affirmed the presence of a strong and clear relationship between ICT and HDI. Gupta et al. (2019) employed panel fixed effects modelling to examine how advancements in ICT could support human capital development, focusing on South Asia from 2000 to 2016. The findings of the empirical analysis point to strong positive connections between internet diffusion, mobile usage, technical readiness, and the HDI. Furthermore, recent research has documented that different ICT indicators (i.e., internet subscriptions, broadband, and mobile phone users) have a positive link with human development (Acheampong et al., 2022). Building on previously stated arguments, this study formulates hypotheses regarding the relationship between ICT and the HDI.

H3: ICT has a *significant impact on the HDI*.

2. Methods

2.1 Model specification

To investigate the relationships between ICT, SCM performance, health-care and HDI in South Asian countries from 2007 to 2021, this study took up the definite models followed by previous literature as follows:

$$SCM_{i,t} = \gamma_0 + \gamma_1 ICT_{i,t} + \gamma_2 Cap_{i,t} + \\ + \gamma_3 EMP_{i,t} + \gamma_4 FD_{i,t} + \mu_{it} \quad (1)$$

The first estimated the impact of ICT diffusion as a single composite index of SCM performance, measured through a logistic performance index in the context of South Asian economies. Furthermore, to investigate the role of individual ICT indicators in SCM performance, we treated the three ICT indicators separately as explanatory variables in Model 2.

$$SCM_{i,t} = \gamma_0 + \gamma_1 FBB_{i,t} + \gamma_2 MOTD_{i,t} + \\ + \gamma_3 INTU_{i,t} + \gamma_4 Cap_{i,t} + \gamma_5 EMP_{i,t} + \\ + \gamma_6 FD_{i,t} + \mu_{it} \quad (2)$$

The third model exhibited the association between health-care expenditures and the composite and communication technology index with the help of other control variables. $HC\_Exp_{i,t}$ is the dependent variable and $ICT_{i,t}$ is the independent variable in this model.

$$HC\_Exp_{i,t} = \gamma_0 + \gamma_1 ICT_{i,t} + \gamma_2 Cap_{i,t} + \\ + \gamma_3 EMP_{i,t} + \gamma_4 FD_{i,t} + \mu_{it} \quad (3)$$

$$HC\_Exp_{i,t} = \gamma_0 + \gamma_1 FBB_{i,t} + \gamma_2 MOTD_{i,t} + \\ + \gamma_3 INTU_{i,t} + \gamma_4 Cap_{i,t} + \gamma_5 EMP_{i,t} + \\ + \gamma_6 FD_{i,t} + \mu_{it} \quad (4)$$

The fourth model was developed to test the individual effects of the ICT indicators (fixed broadband subscription, mobile phone subscribers, and internet users) on health-care expenditures in South Asian economies.

$$HDI_{i,t} = \gamma_0 + \gamma_1 ICT_{i,t} + \gamma_2 Cap_{i,t} + \\ + \gamma_3 EMP_{i,t} + \gamma_4 FD_{i,t} + \mu_{it} \quad (5)$$

The fifth model was developed to test the effect of composite ICT on HDI. $HDI_{i,t}$ is the dependent variable, and $ICT_{i,t}$ is the independent variable.

$$HDI_{i,t} = \gamma_0 + \gamma_1 FBB_{i,t} + \gamma_2 MOTD_{i,t} + \\ + \gamma_3 INTU_{i,t} + \gamma_4 Cap_{i,t} + \gamma_5 EMP_{i,t} + \\ + \gamma_6 FD_{i,t} + \mu_{it} \quad (6)$$

In the above model, $HDI_{i,t}$ is the dependent variable, whereas $FBB_{i,t}$, $MOTD_{i,t}$, and $INTU_{i,t}$ are independent variables. To examine the more pronounced impact of ICT indicators, we developed a sixth model. Furthermore, in all models, three different control variables (i.e., *Cap*, *EMP*, and *FD)* were used that were consistent with the relevant studies (Acheampong et al., 2022; Hussain et al., 2021). Capital stock (*Cap*) was added based on the convergence and balanced growth theory, which suggested that economies with diverse capital stock experience distinct growth paths (Hussain et al., 2021). Hussain et al. (2021) also claimed that all South Asian economies are populous and labour-abundant, and the role of the labour force is the key element for country outcomes. Hence, we added capital stock (*Cap*) and the number of persons engaged (*EMP*) as control variables in all empirical models. Finally, by adding domestic credit to the private sector ratio (*FD*), as per the recommendations of Acheampong et al. (2022), *FD* was used as a control variable by considering the major determinants of health-care and *HDI*. The complete details of these variables are presented in Tab. 1.

ICT is discussed extensively in the literature; its effects on human life are undeniable, and it touches almost every aspect of our lives (Acheampong et al., 2022; Dutta et al., 2019). In our study, we developed a composite ICT index through PCA based on fixed broadband

subscriptions, mobile phone subscribers, and internet users. An evaluation of the total impact of ICT indicators on the SCM performance, HC, and HDI of South Asian economies was the main objective of developing the composite index. The following equation was used to calculate the composite index for the three ICT indicators:

$$ICT = \sum_{i=1}^{3} a_{ij} \frac{X_{ij}}{SD_i} \quad (7)$$

where: *ICT* exhibits the composite index of the three ICT indicators; X_{ij} exhibits the i^{th} variable (*FBB*, *MOTD*, and *INTU*) at the j^{th} year; *SD* exhibits the standard deviation; and a_{ij} represents the factor load obtained through PCA.

2.2 Data source

Seven South Asian economies (Pakistan, India, Bangladesh, Sri Lanka, Maldives, Bhutan, and Nepal), ICT indicators, SCM performance, HC, HDI, and other control variables were combined into a balanced panel dataset. Initially, 18 years of data were collected from 2004 to 2021; however, because SCM performance data were first published by the World Bank in 2007, the sample was restricted to 2007. Hence, this sample covered 15 years of data, ranging from 2007 to 2021, and the estimated results were computed based on 105 country-year observations. We did not consider Afghanistan in this sample (South Asian Economies) due to the unavailability of a sufficient number of observations for the required period.

2.3 Approaches

The primary objective of this study was to explore the course of association between ICT, SCM performance, HC, and HDI. The first stage in these investigations was to determine the integration of all data series in the same order. Previous studies used a wide range of unit root tests to assess whether a series has a unit root issue (Dutta et al., 2019; Hussain et al., 2021; Nazir, 2022). The panel unit root test possesses many advantages; it yields a larger amount

Tab. 1: Variables description (frequency: 2007–2021)

Notation	Description	Source
Dependent variables		
$SCM_{i,t}$	Supply chain management performance measured through logistic performance index for country *i* at time *t*	World Bank
$HC\_Exp_{i,t}$	Per capita health-care expenditures for country *i* at time *t*	World Bank
$HDI_{i,t}$	Human development index	World Bank
Independent variables		
$FBB_{i,t}$	Fixed broadband subscriptions (per 100 inhabitants)	World Bank
$MOTD_{i,t}$	Mobile-phone subscribers (per 100 inhabitants)	World Bank
$INTU_{i,t}$	Internet users as % of the total population	World Bank
$ICT_{i,t}$	Composite index of *FBB*, *MOTD*, *INTU*, developed with the help of principal component analysis (PCA)	Authors calculations
Control variables		
$CAP_{i,t}$	Capital stock in current US dollars	Penn World Tables (PWT)
$EMP_{i,t}$	Numbers of country's person engaged	Penn World Tables (PWT)
$FD_{i,t}$	Ration of domestic credit to the private sector	World Bank

Note: Some of SCM performance values are missing in World Bank dataset, to match the SCM performance data with core ICT indicators take the preceding value of their respective countries to fill the gaps of the SCM performance variable.

Source: own

of point data, enhances the value of the degree of freedom, and dampens multicollinearity among regressors. Therefore, we applied the most popular unit root test, the Phillip-Perron-Fisher unit root test, which was developed to check the stationarity of selected variables (Choi, 2001; Maddala & Wu, 1999). The *p*-values from the other unit-root tests were combined into a single test. If the *p*-value for cross-section I is considered, we obtained the following asymptotic results:

$$-2\sum_{i=1}^{N}\log(\pi_1) \rightarrow X_2^2 N \tag{8}$$

This test operates on the null hypothesis "There is a unit root problem;" thus, rejecting *H0* corroborates that the series does not possess a unit root issue.

The next step was to look for co-integration among the specified variables when it has been shown that all of the suggested data series exhibit the same degree of integration. The two nonstationary series are said to be cointegrated if they have linear combinations. The Pedroni panel co-integration test was used to examine co-integration (1999, 2004). Two distinct sets of test statistics, one based on panel test statistics within dimensions and the other on test statistics between dimensions, were provided by the Pedroni co-integration. Starting with the estimate of the panel regression equation shown below, a Pedroni test was performed.

$$\begin{aligned} &Y_{i,t} = \alpha_i + \textstyle\sum_{j=1}^{p_i}\beta_{i,j}X_{i,j,t} + \mu_{i,t} \text{ and} \\ &\mu_{i,t} = p_i\,\mu_{i(t-1)} + w_{i,t} \end{aligned} \tag{9}$$

where: $Y_{i,t}$ and $X_{i,j,t}$ represent the observable variables; $\mu_{i,t}$ is the disturbance term from panel regression; $\beta_{i,j}$ coefficients would allow for country specific fixed-effects; and α_i would allow for country-specific fixed effects.

In addition to requiring some cross-sectional specifications and regressing the variables, Pedroni tests also permit heterogeneity for intercepts in the co-integration equations. The seven test statistics calculated by Pedroni (1999, 2004) are the panel v, panel rho, panel pp, panel ADF, group rho, group pp, and group ADF statistics. The asymptotic normal distribution provided by the relevant group/panel co-integrated statistics was followed by all seven tests. Additionally, Pedroni (1999) demonstrates that the two values of the group ADF and panel ADF statistics offer convincing proof of the co-integration relationship between the variables in the context of a small sample. The Pedroni test's rejection of the null hypothesis, no co-integration, verified that there is a long-term link between the variables. Additionally, we examined the Kao residual co-integration test (Kao, 1999) under the null hypothesis of no co-integration in homogeneous and heterogeneous panels to confirm the findings of the Pedroni panel co-integration test. The Kao panel co-integration method devised by Kao (1999) was used to verify the existence of residual-based co-integration across all variables. These tests use techniques intended to determine whether a unit root exists in the residuals of the cointegrating regressions among the panel data. The following examples show how panel co-integration works.

$$\chi_{i,t} = \alpha_i + \gamma_{i,t}\,\beta + \omega_{i,t} \tag{10}$$

where: i = 1, …, N; t = 1, …, T, ε_i – individual constant term, β – slope parameter; $\omega_{i,t}$ – stationary distribution; $\chi_{i,t}$ and $\gamma_{i,t}$ – integrated process of order *I* (1) for all *i.*

The panel fully modified ordinary least squares (FMOLS) technique based on Pedroni's (2000) approach is employed if all variables are found to be co-integrated, which indicates that they have an equilibrium/long-run link. Strong evidence from the literature permits the application of FMOLS to ensure the existence of long-term relationships among the suggested variables. This method yielded asymptotically unbiased long-term estimates. Moreover, it has numerous other benefits such as serial correlation (SE), endogeneity (EE), and cross-sectional heterogeneity. The panel dynamic ordinary least squares (DOLS) is another FMOLS approach (Faff et al., 2016; Nazir et al., 2022). However, Pedroni (2000) suggested that the FMOLS technique, which requires fewer assumptions, is more robust than the DOLS method, and Kao (1999) further confirmed that when panel data are constrained, as in the current study, DOLS results may suffer from a reduction in the degree of freedom. In these situations, FMOLS has proven to be effective in forecasting long-run coefficients. FMOLS also employs semi-parametric and residual autocorrelation adjustments.

3. Results and discussion

Tab. 2 presents the results of the unit-root estimations. The Phillip Perron (Kuppusamy et al., 2009) Fisher's unit root test was applied to determine the outcomes. The result revealed that at level *I* (0), all the variable series including ($SCM_{i,t}$, $HC\_Exp_{i,t}$, $HDI_{i,t}$, $FBB_{i,t}$, $MOTD_{i,t}$, $INTU_{i,t}$, $ICT_{i,t}$, $CAP_{i,t}$, $EMP_{i,t}$, and $FD_{i,t}$) were not stationary under the null hypothesis "There is a unit root problem." Therefore, we also took the first difference of all data series and found that all of them were stationary at the 1st difference, which implies that data series are integrated at order one *I* (1). Once it was proven that all series were integrated at *I* (1), the next step was to verify whether the variable has a long-run relationship. To achieve this objective, we used the panel Pedroni co-integration approach (2004).

Tab. 2: Unit root analysis

Notation	PP Fisher unit root (test values)			
	At level		At 1st difference	
	PP – Fisher chi-square	PP – Choi *Z* stat	PP – Fisher chi-square	PP – Choi *Z* stat
$SCM_{i,t}$	4.7820	2.7098	28.5405**	−2.3257**
$HC\_Exp_{i,t}$	0.8584	7.0808	88.8305***	−6.5609***
$HDI_{i,t}$	19.5860	0.1751	62.4260***	−5.6928***
$FBB_{i,t}$	3.0026	4.7723	22.5701*	−1.7161**
$MOTD_{i,t}$	4.4559	3.6103	22.5926*	−2.1887**
$INTU_{i,t}$	0.5452	7.8405	47.2434***	−4.0839***
$ICT_{i,t}$	18.5630	−1.5329	40.8649***	−3.6936***
$CAP_{i,t}$	0.0046	11.8490	1.9674	−2.1013**
$EMP_{i,t}$	15.5880	2.7730	37.0665	−2.6080***
$FD_{i,t}$	10.2570	1.4313	44.8030***	−4.4805***

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Source: World Bank & PWT Data

The results of the panel co-integration for all four models are presented in Tab. 3. The outcomes of Models 1 and 2 reveal that the majority of the statistical values (five out of seven) are significant, which confirms that ICT, in the form of an index and individual indicators, has an equilibrium relationship with supply chain performance. Further, results of Models 3 and 4, which check the impact of ICT indicators individually as well as in the form of a combined index on health-care expenditures with a set of control variables, reveal that 4 out of 7 statistic values (i.e., panel PP-statistics, panel ADF-statistics, group PP-statistics, and group ADF-statistics) are statistically significant at different levels. This shows that the majority of statistics values are significant and reject the null hypothesis of "there is no co-integration. Therefore, we conclude that there is one co-integration relationship between the variables (see the results of Models 3 and 4 in Tab. 3). Furthermore, the outcomes of Models 5 and 6, which examine the influence of ICT indicators individually and in the form of an index on HDI with numerous control variables, highlight that most statistical values are significant and reject *H0.* This indicates the existence of a long-run or equilibrium relationship between ICT and HDI.

In addition, to enhance the robustness of the findings on the co-integration relationship, we employed another panel co-integration approach, the Kao residual (Kao, 1999), to confirm the existence of long-run associations

Tab. 3: Pedroni co-integration analysis

	Statistics					
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Within dimensions						
Panel v-statistics	4.2244***	6.1080***	−0.6188	−0.4789	0.1230	11.2622***
Panel rho-statistics	0.5472	1.8092	1.2357	2.7019	2.0957	2.9884
Panel PP-statistics	3.2424**	2.8096**	−2.1586**	−7.3979***	−2.1867***	−9.9643***
Panel ADF-statistics	−5.1067**	−1.5478*	−2.1507**	−2.9161***	−2.3429***	−3.6996***
Between dimensions						
Group rho-statistics	0.8370	0.0676	2.1905	3.1287	2.4707	3.7869
Group PP-statistics	−1.3388*	−4.2890**	−3.2716***	−14.0574***	−1.7097**	−14.2589***
Group ADF-statistics	−6.8876**	−2.9098**	−2.6310***	−3.4317***	−3.3116***	−4.1390***

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Source: World Bank & PWT Data

Tab. 4: Kao residual co-integration analysis (test: ADF)

	***t*-statistics**	**Probability**	**Residual variance**	**HAC variance**
Model 1	−1.75***	0.0684	1,426.11000	1,971.18000
Model 2	−4.22***	0.0005	1,451.43000	1,250.50000
Model 3	−2.62**	0.0452	1,644.59000	1,784.13000
Model 4	−3.33***	0.0004	1,371.21000	1,339.05000
Model 5	−1.69*	0.0942	0.00006	0.00011
Model 6	−3.77***	0.0001	0.00003	0.00004

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Source: World Bank & PWT Data

among the variables. The outcomes of the Kao residual co-integration are presented in Tab. 4. The results for all models showed that all statistical values were significant, rejecting the null hypothesis and confirming the long-run relationships among the variables (Tab. 4).

Once it was proven that the data series were integrated in order one and had an equilibrium/co-integration relationship, the next step was to examine whether the considered variables had a negative or positive long-run association. For this purpose, the econometric rule that employs the panel co-integration regression technique FMOLS to determine the direction of relationships was used. The estimations in columns 1 and 2 revealed the outcomes

of Models 1 and 2, respectively, where the ICT index and its individual indicators were regressed on SCM performance with a set of control variables. The results of Model 1 showed that the ICT index positively influences SCM performance ($p < 0.01$). Model 2 concluded that all ICT indicators are positively associated with SCM performance at different significance levels. These results are consistent with those of Yang et al. (2022) and Zhang et al. (2016), who documented the positive role of ICT in asset management, operational efficiency, transportation infrastructure, and agility, all of which translate into SCM performance. In addition, the results of Models 1 and 2 align with those of Shiralkar et al. (2021) and Ma et al. (2023), who showed that ICT adoption statistically improves SCM performance. Specifically, Shiralkar et al. (2021) contended that sharing information is the key success element of the supply chain process and that this is only possible through ICT penetration. They concluded that ICT use dampens short-term consequences and helps design effective approaches that make supply chains profitable in the long run (Ma et al., 2023; Shiralkar et al., 2021). This leads to ICT diffusion, enabling the transmission of contextual information, which helps partners make optimal decisions and act promptly in the supply chain process.

Furthermore, Model 3 reported the estimations in which the ICT index is regressed on health-care expenditures with some control variables. The results revealed that the response of health-care expenditure to ICT diffusion is positive and significant ($p < 0.01$) in the estimated coefficients. This outcome supports the argument of Omotosho et al. (2019), who concluded that electronic health is an important application of ICT and has made significant contributions to health-care delivery by providing high-quality health-care and ubiquitous access at a lower cost.

It is pertinent to mention that in Maslow's hierarchy of needs, health-care expenditure aligns with the fundamental tier of physiological needs. This level considers essentials, such as food, water, shelter, and health-care required for survival, as the basic needs preferred by residents of developing or low-income countries. Thus, the positive influence of ICT on health-care expenditures confirms Maslow's theory in the context of South Asia. These results are consistent with the conclusion of Dutta et al. (2019), who documented that the ICT index has a long-term positive association with health outcomes in a sample of 30 Asian economies. A concurrent study by Zhang et al. (2022) also supports our findings by concluding that, at the macro level, ICT penetration has a positive effect on health outcomes by increasing health-care expenditures. They claimed that ICT is a key indicator with the potential to motivate governments to enhance health-care expenditure, which in turn ultimately leads to healthy lives. Further, Model 4 investigated the impact of three ICT indicators (i.e., $\ln\_FBB_{i,t}$, $\ln\_MOTD_{i,t}$, $\ln\_INTU_{i,t}$) on health-care expenditure with different control variables. The results show that, with a coefficient value of 0.0149, fixed broadband subscriptions positively influence health-care expenditure. Similarly, with coefficients of 0.0575 and 0.2072, respectively, the outcomes also highlight that both mobile phone subscribers and internet users have a positive link with health-care expenditure (Tab. 5). Notably, internet use has a more pronounced positive impact on health-care expenditures than other ICT indicators. These results are in line with the outcomes of Rana et al. (2020) and Qureshi (2016), who contended that, in the context of low-income economies, the use of ICT, especially the internet and mobile devices, plays an instrumental role in improving health-care provisions and preventing the spread of different viruses. Specifically, Rana et al. (2020) document that the widespread accessibility of ICT in the form of the internet and mobile devices has a statistically positive influence on health-care expenditure. They also proved that the role of the internet is much more pronounced in enhancing health-care expenditure relative to mobile phones. Furthermore, in both Models 3 and 4, the value of the adjusted R^2 was approximately 99%, which confirms the goodness of the models. This indicated that 99% of the variation in Y was significantly explained by the linear models in this study. Taken together, the results of Models 3 and 4 show that ICT indicators, as well as their combined form, have a positive association with health-care expenditure. These findings are in line with Maslow's hierarchy of needs theory that residents of emerging countries are more concerned about lower-order needs (i.e., health-care).

Furthermore, Models 5 and 6 in Tab. 5 reported the estimations of regression Equations

(5–6), which examined the influence of ICT indicators in the form of a combined index and individual forms on HDI with a set of control variables, respectively. Model 5 showed that ICT diffusion in the form of an index has a positive and significant (p < 0.01) influence on human development in South Asian economies. This result is similar to the findings of Nevado et al. (2019) and Machfud and Kartiwi (2018), who showed that ICT advancement is significantly associated with quality of life because digitalised citizens are happy with their technological capacity. They state that when governments invest heavily in R&D and innovative projects, they create value for citizens, especially in developing economies. Specifically, in their comparative analysis, Nevado et al. (2019) revealed that human development is much more pronounced in regions with greater ICT use than in those with lower ICT use.

Tab. 5: Regression estimations (method: FMOLS)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	SCM	*SCM*	*HC_Exp*	*HC_Exp*	*HDI*	*HDI*
Ln_$ICT_{i,t}$	0.0318***		0.0417***		0.0097***	
	(8.8500)		(6.4700)		(28.4400)	
Ln_$FBB_{i,t}$		0.0432*		0.0149***		−0.0032***
		(1.9700)		(4.6500)		(−13.7800)
Ln_$MOTD_{i,t}$		0.0736**		0.0575***		0.0208***
		(2.2600)		(9.0300)		(45.0500)
Ln_$INTU_{i,t}$		0.1871***		0.2072***		0.0219***
		(12.8300)		(32.8100)		(47.7400)
Ln_$CAP_{i,t}$	0.0047***	0.0073***	0.9604***	0.1890***	0.1283***	0.0275***
	(4.7500)	(4.8800)	(23.3100)	(9.4100)	(58.7600)	(18.8500)
Ln_$EMP_{i,t}$	0.1140**	0.1290**	0.3489***	0.4697***	0.0862***	0.1313***
	(6.6000)	(6.1500)	(2.5700)	(10.9900)	(11.9800)	(42.3400)
Ln_$FD_{i,t}$	0.0314***	0.0232***	0.4035***	0.1854***	0.0469***	0.0131***
	(9.1300)	(9.5500)	(10.1700)	(15.0600)	(22.3300)	(14.6900)
***R*-squared**	0.9972	0.9231	0.9891	0.9953	0.9807	0.9845
Adjusted *R*-squared	0.9924	0.9199	0.9876	0.9945	0.9781	0.9819

Note: *** p < 0.01, ** p < 0.05, * p < 0.1 (t-statistics are reported in parenthesis).

Source: World Bank & PWT Data

In Model 6, the results revealed that individual indicators of ICT, that is, fixed broadband subscriptions with a coefficient value of −0.0032 had a negative and significant association with human development (p < 0.01). By contrast, the other ICT indicators, MOTD and INTU, had a positive influence on human development. The coefficient values (0.0208 and 0.0219) of $MOTD_{i,t}$ and $INTU_{i,t}$ respectively, showed that internet use has a slightly higher impact on human development in South Asian economies (see the results of Model 5; Tab. 5). This positive association of mobile phone subscribers and internet users with HDI aligns with the conclusion of Gupta et al. (2019), who documented strong positive connections between internet diffusion and mobile usage with HDI. These results are also in line with the outcomes of Acheampong et al. (2022) and Adegboye et al. (2022), who concluded that mobile phone and internet use positively affect the development of human life. In particular, Adegboye et al. (2022) documented that ICT indicators (i.e., mobile phone and internet use) directly, as well as with equal

resource distribution under the instrumental variable approach, positively impact inclusive Human development in middle-income economies. Similarly, in their comparative analyses, Acheampong et al. (2022) documented that compared to Latin America-Caribbean and Sub-Saharan Africa, ICT diffusion is much more likely to influence HDI in South Asia. Hence, promoting ICT access, particularly in developing economies (similar to ours), is believed to be a marker of human development. In addition, the adjusted R^2 value of Models 5 and 6 were approximately 98%, which revealed that only 2% of the variations in the outcome variables were not explained by the models.

Overall, this study contributes to the literature by comprehensively extending the theoretical and empirical literature on ICT indicators, SCM performance, health-care expenditure, HDI, and developing economies in a single study. Further, the use of three different ICT indicators (i.e., fixed broadband subscriptions, mobile-phone subscribers, and internet users) individually as well as in the form of a composite index as key independent variables, and the selection of fastest-growing regions (in the context of technology and innovation), that is, South Asia, for this study are the main novelties of the paper.

Conclusions

The critical role of ICT diffusion in promoting supply chain performance, health-care facilities, and HDI has been neglected, especially in developing South Asian economies. South Asian countries are among the fastest-growing countries worldwide in terms of ICT diffusion. Drawing upon Maslow's hierarchy of needs, which contends that individuals in developing or lower-middle-income nations prioritise foundational needs such as transportation, education, and health-care, this study examined whether ICT and its individual components promote supply chain performance, health-care expenditures, and HDI in South Asian countries. The study used three indicators (i.e., fixed broadband subscriptions, mobile phone subscribers, and internet users) individually as well as in the form of a composite index developed through PCA to measure ICT infrastructure. Panel co-integration and fully modified ordinary least squares techniques were applied to investigate the long-run associations among the proposed variables. The findings revealed that ICT diffusion has a positive long-run association with supply chain performance, health-care expenditure, and HDI. All three individual indicators were positively associated with supply chain performance and health-care expenditure. Furthermore, two (MOTD and INTU) of the three individual ICT components were positive, while one (FBB) was negatively associated with HDI in South Asian economies. Interestingly, the results also revealed that among other ICT indicators, the internet has a more pronounced impact on the promotion of supply chain performance, health-care expenditure, and HDI.

These findings suggest that ICT diffusion plays a pivotal role in boosting supply chain performance, health-care facilities, and living standards in emerging South Asian economies. Moreover, following Maslow's hierarchy of needs, it was observed that people in lower-middle-income countries were more concerned about their basic physical needs. Therefore, policymakers should devise specific policies to boost the ICT infrastructure in the country (with a keen focus on internet diffusion), which will not only improve operational efficiency and create better infrastructure, but also handle the issues of a fragile health-care system and improve the standard of living of the general population. Furthermore, South Asian countries should engage in technology-centric diplomacy and foster ties with nations that possess advanced technological expertise. This will help them advance their ICT infrastructures and improve their well-being. The findings of this study also provide solid grounds for politicians to reallocate funds to ICT-related projects, aiming to improve supply chain performance, health-care systems, and HDI. This can reshape budget priorities and funding allocations.

The generalisation of these results to other developing nations should be considered after careful analysis of the governance, cultural, infrastructural, and technological penetration dynamics of the country. Furthermore, South Asia is comprised of diverse countries with unique political, cultural, and economic landscapes. This study might have overlooked the nuanced differences within these countries that could affect how ICT impacts different aspects of development. Finally, disparities in ICT diffusion and access within and between South Asian countries may skew the findings of the present study, affecting the equitable distribution of benefits across different segments of society.

Future research should focus on sub-regional analysis to identify specific factors

influencing the relationship between ICT, supply chain performance, health-care, and HDI, considering diverse socioeconomic and cultural contexts. Similarly, a focus is placed on comparative studies with other regions to benchmark and identify unique challenges. Exploring the role of ICT diffusion in educational institutions, B2B transactions, and green economy initiatives, particularly in the post-COVID-19 era would also be an interesting topic.

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The nexus between logistics competitiveness, logistics carbon emission efficiency and industrial structure upgrading: Evidence from China

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Abstract: *The rapid development of the logistics industry has made considerable contributions to China's industrial transformation and economy soaring. However, the improvement of logistics competitiveness often leads to high carbon emissions. Understanding the dynamic relationship between logistics competitiveness, logistics carbon emission efficiency, and industrial structure upgrading is of great significance for promoting the high-quality development of regional logistics under the context of the carbon-neutrality target. This study employed the panel vector autoregression (PVAR) model to analyse the relationship between logistics competitiveness, logistics carbon emission efficiency, and industrial structure upgrading based on the data from 30 provincial – regions in China for the period of 2007–2021. Meanwhile, the impulse response function was used to reflect the dynamic relationship between the variables of the model, and using variance decomposition to display the percentage change of one variable affected by another variable. The results show that there are self-adjustment effects in logistics competitiveness, logistics carbon emission efficiency, and industrial structure upgrading. Besides, a U-shaped effect is observed from the effect of logistics competitiveness on logistics carbon emission efficiency. It shows a negative impact in the short term and a positive impact in the long term. And it is the same as the effect of logistics carbon emission efficiency on logistics competitiveness, indicating the existence of the time-lag effect. Moreover, upgrading industrial structures has a positive promoting effect on both logistics carbon emission efficiency and logistics competitiveness. Thus, this research provides a unique perspective by exploring how to improve the development of the logistics industry by discussing the nexus between logistics competitiveness, logistics carbon emission efficiency, and industrial structure upgrading.*

Keywords: *Logistic competitiveness, carbon emission efficiency, industrial structure, panel vector autoregression (PVAR) model, green development.*

JEL Classification: *C33, O47, R10.*

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Introduction

As a crucial service industry connecting production and consumption (Zhou et al., 2024), logistics has received support from national industrial policies and become an essential sector in the national economy. Over the past few decades, the logistics industry in China has been booming, with the total value of social logistics goods increasing from 75.23 trillion yuan (equal to 10.19 trillion USD) in 2007 to 347.6 trillion yuan (equal to 49.52 trillion USD) in 2022, achieving a compound annual growth rate of 45.33%. In order to better assess the impact of policies and measure the level of regional logistics competitiveness, different indicator systems have been employed to measure the development of regional logistics, including the analytic hierarchy process (Özceylan et al., 2016), grey relational analysis (Yang & Chen, 2016), and ESDA (Jing & Cai, 2010). However, due to the vast territory of China, there are significant disparities among regions in terms of the environment, economy, and logistics infrastructure. The existing literature primarily focuses on evaluating the competitiveness between different countries (Ambrosini & Routhier, 2004; Ozmen, 2019), making it challenging to objectively and effectively assess the logistics competitiveness across different regions in China. Therefore, there is still room for further expansion regarding methodology and indicators.

Besides, the logistics industry plays a role in the development of the national economy. However, it consumes a large amount of energy, making it one of the main sources of carbon dioxide emissions (Rashidi & Cullinane, 2019). According to the China Energy Statistical Yearbook, published by the Chinese government (National Bureau of Statistics, https://www.stats.gov.cn/), energy consumption in the logistics industry has increased from 20.643 million tons of standard coal in 2007 to 43.935 million tons of standard coal in 2021, accounting for about 18% of the country's total carbon emissions. The pressure for energy conservation and emission reduction in the logistics industry has significantly increased (Jiang et al., 2020). In order to establish a sustainable economy, it is imperative to enact a range of strategies for mitigating the increasing carbon emissions.

Improving logistics competitiveness can help enterprises innovate and invest more money in developing green technologies to reduce carbon emissions. However, the expansion of the logistics industry implies higher energy consumption and carbon emissions. Scholars have yet to reach a consensus on the impact of logistics competitiveness on carbon emissions. Some believe that the development of logistics has a positive impact on carbon emissions (Yang et al., 2019; Zhang et al., 2018), while others argue that logistics competitiveness will suppress carbon emissions (Chen & Wu, 2022; Suki et al., 2021). Karaduman et al. (2020) pointed out that this relationship was non-linear, showing a promotion-suppression pattern similar to the Environmental Kuznets curve. Therefore, scholars provide mixed results on whether logistics competitiveness will increase carbon emissions.

Also, the logistics industry belongs to the tertiary industry, and the adjustment of industrial structure will greatly affect the development of the logistics industry. Primary and secondary industries often dominate the traditional industrial structure, relying on industries with large-scale energy consumption and high carbon emissions (Wu et al., 2021). The current research framework rarely includes industrial structure upgrading as a key factor affecting the logistics industry and carbon emission efficiency. Therefore, this study aims to explore whether logistics competitiveness has an impact on the carbon emission efficiency of the logistics industry and, if so, what impact it has. How does the upgrading of the industrial structure impact logistics competitiveness and the efficiency of logistics carbon emissions? Based on the lack of existing literature, this study aims to investigate the interaction mechanism between logistics competitiveness, logistics carbon emission efficiency, and industrial structure upgrading. The entropy approach was employed to construct an index system that objectively assesses logistics competitiveness. The super-SBM model was utilized to evaluate the carbon emission efficiency of the logistics industry, laying the foundation for further investigation using the panel vector autoregression (PVAR) model to explore the nexus between logistics competitiveness, logistics carbon emission efficiency, and industrial structure upgrading.

The remainder of this study is as follows. Section 1 is a review of existing literature. Section 2 includes the measurement of variables, data description, and model construction.

Section 3 presents a set of empirical results and discussion. The last section draws conclusions.

1. Theoretical background

Current studies focus on the relationship between logistics competitiveness and carbon emission efficiency, logistics competitiveness and industrial structure upgrading, and logistic carbon emission efficiency and industrial structure upgrading by using empirical analysis. This part reviews the research themes, indicators, and methods of previous literature.

1.1 Logistics and carbon emission nexus

With attention to environmental issues and the rapid development of logistics, many scholars have studied this area. Most of them have focused on the impact of carbon emissions. They investigate the analysis by examining the influence of the logistics industry's gross domestic product (GDP), e.g., Yu et al. (2023) constructed the BPNN model to analyse the influential factors of carbon emissions in China. They found that increasing the GDP of the logistics industry could significantly impact energy consumption and carbon emissions. Chen and Wu (2022) applied the Tapio decoupling model to analyse the decoupling effect between carbon emissions and the economy in the Heilongjiang Province of China. Moreover, the results showed that the primary determinant impeding the expansion of carbon emissions in the logistics sector was the advancement of logistics. On the contrary, Zhang et al. (2018) found that the most important factor contributing to the increase in carbon emissions was the added value of the logistics industry. Over time, the development of the logistics industry has increased its reliance on carbon dioxide emissions (Sun & Liu, 2016). The disorderly development of numerous express delivery companies and urban distribution has led to a rise in carbon emissions (Zhang et al., 2021).

Meanwhile, as pointed out by Xu et al. (2022), the impact of logistics on carbon emissions was non-linear. Their research revealed that, prior to 2015, the growth of the logistics sector in China contributed to increased carbon emissions. However, changes in the logistics industry's patterns inhibited subsequent growth. Zaman and Shamsuddin (2017) investigated the relationship between logistics development and economies of scale in European countries. Their findings revealed that logistics competitiveness had dual effects.

Based on logistics performance, Karaduman et al. (2020) found that logistics had a significant positive impact on carbon emissions in Balkan countries. Conversely, Suki et al. (2021) found that, in the long run, the logistics performance index had a significant negative impact on carbon emissions.

Another group of scholars investigates the impact of carbon emissions on logistics. They found that CO_2 exacerbates environmental pollution, thereby increasing transport costs and disruptions in transportation, which had various impacts on the logistics industry (Zhu et al., 2008). Also, the study conducted by Akram et al. (2023) on Asian economies indicated that carbon dioxide emissions inhibited logistics performance.

1.2 Logistics and industrial structure nexus

There is a close relationship between logistics and industrial structure. The magnitude of logistics competitiveness could assist cities in providing a decision-making basis (Liu et al., 2020) for upgrading industrial structures (Zhao & Xie, 2022). Gao et al. (2018) conducted a linear regression model to evaluate the correlation between logistics and industrial structure.

Also, the industrial structure had a significant impact on logistics development (Fan et al., 2022). It was closely related to the high-quality growth of regional logistics in China (Chen & Zhang, 2022). By upgrading the industrial structure, the efficiency of low-carbon logistics could be improved (Ye et al., 2022; Zhao, 2022). Guo and Li (2023) found that the industrial structure had been impacted by the logistics efficiency in central China through the panel Tobit model. For the contribution of different industries to the development of logistics, Liu et al. (2018) pointed out that the primary and secondary industries had a higher variance contribution rate to the development of the logistics industry compared to the tertiary industry. Zhang et al. (2022b) believed that the proportion of tertiary industry structure was conducive to the development of logistics enterprises.

There is also another viewpoint. According to Li et al. (2023), industrial structure upgrading promoted the formation of local logistics network structures but would inhibit the development of logistics in the surrounding areas due to the siphon effect.

1.3 Industrial structure and carbon emission nexus

The research conclusions of many scholars show that industrial structures can impact carbon emissions. Specifically, a tertiary industry-dominated industrial structure can suppress carbon emissions. Zhang et al. (2014) investigated the primary factor influencing carbon emission intensity from 1978 to 2011 in China. They found that the proportion of added value in the tertiary industry to GDP significantly curbed carbon intensity. Guo and Wang (2022) discovered that the industry population had a significant impact on carbon emissions in the logistics industry by using the improved STIRPAT model and SLM. Sun et al. (2022) utilised the three-dimensional grey correlation analysis model and found that the influence of the tertiary industry on carbon emissions varied across different regions.

Some scholars have studied the impact of the secondary industry on carbon emissions. They found that the proportion of the secondary industry would have a significant positive impact on carbon emissions (Zeng & Yi, 2023). Moreover, it was the main driving factor for the increase in carbon emissions within the three industries (Zhang & Da, 2015).

While a growing body of research supports that upgrading industrial structures can curb carbon emissions, a few studies suggest otherwise. For example, Huang and Ling (2021) believed that industrial restructuring was a long process with a lag effect. Moreover, compared with the logistics industry, other industries in China have been transforming much faster. Therefore, upgrading the industrial structure will inhibit the logistics carbon emissions. Some scholars have pointed out that the adjustment of industrial structure has a negative effect on eco-efficiency (Long et al., 2020; Zheng et al., 2022). The upgrading of the industrial structure and the advancement of the tertiary industry would adversely affect the logistics industry's scale in the short term, leading to the decline of regional ecological efficiency (Bai et al., 2022).

In addition, scholars are also interested in the spatial differences between industrial structure and carbon emissions. Tian et al. (2014) found a significant relationship between regional industrial structure and regional carbon emissions. Li et al. (2012) utilized the STIRPAT model and found that the impact of industrial structure on carbon emissions varied across different emission regions. And it remained a significant driving factor. Besides, industrial structure was not the primary influencing factor in high-emission regions.

In summary, there is a lot of literature supporting the relationship between logistics, carbon emission and industrial structure upgrading. However, using the logistics industry's GDP to measure regional logistics development in the literature, as mentioned above, has certain limitations and overlooks the influence of other factors. This study constructs an index evaluation system to evaluate regional logistics competitiveness in multiple dimensions, making the results more credible. Moreover, carbon emissions can reflect energy consumption to some extent. However, considering the carbon emission efficiency that combines local economic development and carbon emissions can help us better study the situation of carbon utilisation in various provinces and autonomous regions. In addition, scholars have different research conclusions on the influence of the relationship between the three chosen variables in this paper. Therefore, this study can further emphasise the following research questions:

RQ1: Will logistics competitiveness have an impact on carbon emission efficiency?

RQ2: How does industrial structure upgrading affect logistics competitiveness and carbon emissions efficiency?

Also, it is worth noting that few scholars have explored the dynamic relationship among logistics competitiveness, logistics carbon emission efficiency, and industrial structure upgrading. So, this study aims to explore the interaction between the above three factors.

2. Research methodology

The purpose of this study is to investigate the nexus between logistics competitiveness, logistics carbon emission efficiency, and industrial structure upgrading by using the PVAR model. Following the existing literature, we first constructed an evaluation index system to measure logistics competitiveness by using the entropy method, and then the super-SBM model was employed to evaluate logistics carbon emission efficiency. Finally, the PVAR model was constructed to observe the dynamic relationship between the selected variables.

2.1 Measurement of logistics competitiveness

According to the previous research of Bajec et al. (2020), Chen (2008), Li et al. (2010), and Zou et al. (2020), we used the entropy weight method to measure the regional logistics competitiveness in China by four aspects: logistics industry infrastructure, the regional economic development level, the capacity of logistics scale, and the informatization levels. The data for each year was standardized according to Formula (1). The specific indicators and the calculated results of weights are shown in Tab. 1.

Tab. 1: Evaluation indices of logistics competitiveness

Level one index	Level two index	Unit	Weight
Logistics industry infrastructure	Length of railways in operation	km	0.0370
	Length of navigable inland waterways	km	0.1096
	Length of highways	km	0.0358
	Possession of civil transport vessels	unit	0.1587
	Length of postal routes	km	0.0809
Regional economic development level	Gross regional product (GRP)	USD 100 million	0.0613
	Per-capita GRP	USD	0.0359
	GRP by tertiary industry	USD 100 million	0.0719
Capacity of logistics scale	Total passenger-kilometers	100 million passenger-km	0.0497
	Total freight ton-kilometers	100 million ton-km	0.0776
	Number of employed persons in transport, storage, and post industry	10,000 persons	0.0509
Informatization levels	Popularization rate of telephones	set/100 persons	0.1545
	Number of broadband subscribers port of Internet	10,000 ports	0.0763

Source: own

The formula for entropy weight method is as follows:

$$X = \frac{X - X_{\min}}{X_{\max} - X_{\min}} + 0.0001 \quad (1)$$

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \quad (2)$$

$$e_j = -k \times \sum_{i=1}^{n} P_{ij} \ln P_{ij} \quad (3)$$

$$g_j = 1 - e_j \quad (4)$$

$$W_j = \frac{g_j}{\sum_{j=1}^{n} X_j} \quad (5)$$

$$S_i = \sum_{j=1}^{n} W_j \times P_{ij} \quad (6)$$

Formula (1) was used to standardize the original data. To avoid errors in subsequent logarithmic calculations, add 0.0001 to the standardized data. P_{ij} represents the normalized value of the i^{th} year for the j^{th} index. e_j is the entropy value of j^{th} index. w_j denotes the weight of the j^{th} indicator. S_i represents the composite score.

2.2 Measurement of logistic carbon emission efficiency

This study utilised the super-SBM model to evaluate logistic carbon emission efficiency in various provinces and autonomous regions. We selected three input indicators. The first

one is capital input, which is expressed by the fixed asset investment in the logistics industry (Wang et al., 2021). The second one is energy input, which is represented by the consumption of coal, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas, natural gas, and electricity converted into standard coal. The third one is labor input, which is measured by the end-of-year employment in the logistics industry of each province. There are two output indicators: the GDP of the logistics industry and carbon dioxide emission. The former is considered the expected output, while the latter is an unexpected output. The carbon dioxide emission is calculated based on the methodology provided by the Intergovernmental Panel on Climate Change (IPCC), and the formula is as follows:

$$C = \sum_{i=1}^{7} E_i \times NCV_i \times CEF_i \times COF_i \times 44/12 + EC \times EF \quad (7)$$

where: C – the carbon emission; E_i – the consumption of the i^{th} energy type converted into standard coal; NCV_i – the average low calorific value of the i^{th} energy type; CEF_i – the carbon content of the i^{th} energy type; COF_i – the carbon oxidation factor of the i^{th} energy type, typically equal to 1; EC – the electricity consumption; EF – the electricity carbon emission factors.

The super-SBM was introduced by TOE (Tone, 2002). The proposed model integrates the strengths of both the super-DEA model and the SBM model. The efficiency values of decision-making units in this model are not constrained to the range of 0–1, allowing for comparability of efficiency when considering unexpected outputs. Thus, it can accurately rank the carbon emission efficiency values of China's provinces, municipalities, and autonomous regions for 15 years. The specific formula is as follows:

$$\begin{aligned} \min \theta = & \frac{1/m \sum_{i=1}^{m} (\bar{x}/x_{ik})}{1/(s_1+s_2)\left(\sum_{p=1}^{s_1} \overline{y^d}/y_{pk}^d + \sum_{q=1}^{s_2} \overline{y^u}/y_{qk}^u\right)} \\ \text{s.t. } & \bar{x} \geq \sum_{j=1,\neq k}^{n} x_{ij}\lambda_j \quad i = 1, \ldots, m \\ & \overline{y^d} \leq \sum_{j=1,\neq k}^{n} y_{pj}^d \lambda_j \quad p = 1, \ldots, s_1 \\ & \overline{y^u} \geq \sum_{j=1,\neq k}^{n} y_{qj}^u \lambda_j \quad q = 1, \ldots, s_2 \\ & \lambda_j \geq 0 \quad j = 1, \ldots, n;\ j \neq 0 \\ & \bar{x} \geq x_k, \quad k = 1, \ldots, m;\ \overline{y^d} \leq y_k^d \quad q = 1, \ldots, s_1;\ \overline{y^u} \leq y_k^u \quad u = 1, \ldots, s_2 \end{aligned} \quad (8)$$

where: s_1 and s_2 represent expected output and unexpected output, respectively. Vector $x \in R^m$, $y^d \in R^{s2}$. X, Y^d and Y^u are matrices, $X = [x^1, \ldots, x^n] \in R^{m \times n}$, $Y^d = [y_1^d, \ldots, y_n^d] \in R^{s_1 \times n}$, $Y^u = [y_1^u, \ldots, y_n^u] \in R^{s_2 \times n}$.

2.3 Measurement of industrial structure upgrading

In this study, the ratio of the added value of the tertiary industry to the regional GDP was selected as an indicator of the industrial structure upgrading of each province and autonomous region.

2.4 Data

This study analysed the panel data on logistics competitiveness, logistic carbon emission efficiency, and industrial structure upgrading for the past 15 years (2007–2021) in 30 provinces and autonomous regions in China (excluding Hong Kong, Macau, Taiwan, and Tibet due to data availability). The data were sourced from the China Statistical Yearbook and China Energy Statistical Yearbook. Since China's Statistical Yearbook does not directly provide data on the logistics industry, we selected statistics data from the transport, storage, and post industries as a substitute for the logistics industry (Liu et al., 2020). And linear interpolation was used to fill in missing values.

2.5 PVAR model

Holtz-Eakin et al. (1988) were the first to propose the panel vector autoregression (PVAR) model. Then it was developed by Love and Zicchino (Love & Zicchino, 2006) and finalised by Abrigo and Love (2016). Compared to the vector autoregression (VAR) model, it takes into account both time and individual effects while also addressing individual heterogeneity (Liu et al., 2021). So, it is feasible to investigate the dynamic relationship between logistics competitiveness, logistics carbon emission efficiency, and industrial structure upgrading. The specific formula of the model is as follows:

$$Y_{it} = \alpha_0 + \sum_{j=1}^{n} \alpha_j Y_{i,t-j} + \beta_i + \theta_t + \varepsilon_{it} \quad (9)$$

where: Y_{it} – the three vectors of logistics competitiveness (LCN), logistics carbon emission efficiency (LCEE), and industrial structure

upgrading (ISU); i – the province; t – the year; α_0 – the intercept term; α_j – the coefficient matrix of lag order j; β_i and θ_t represent the individual effect and time effect, respectively; ε_{it} – the random disturbance.

Formula (9) can be rewritten as three equations according to Lin and Okoye (2023):

$$\Delta ctn_{it} = A_{1i} + \sum_{j=1}^{n} a_{1j}\,\Delta ctn_{i,t-j} + \sum_{j=1}^{n} b_{1j}\,\Delta cee_{i,t-j} + \\ + \sum_{j=1}^{n} c_{1j}\,\Delta is_{i,t-j} + \beta_{1i} + \theta_{1t} + \varepsilon_{1it} \quad (10)$$

$$\Delta cee_{it} = A_{2i} + \sum_{j=1}^{n} a_{2j}\,\Delta ctn_{i,t-j} + \sum_{j=1}^{n} b_{2j}\,\Delta cee_{i,t-j} + \\ + \sum_{j=1}^{n} c_{2j}\,\Delta is_{i,t-j} + \beta_{2i} + \theta_{2t} + \varepsilon_{2it} \quad (11)$$

$$\Delta is_{it} = A_{3i} + \sum_{j=1}^{n} a_{3j}\,\Delta ctn_{i,t-j} + \sum_{j=1}^{n} b_{3j}\,\Delta cee_{i,t-j} + \\ + \sum_{j=1}^{n} c_{3j}\,\Delta is_{i,t-j} + \beta_{3i} + \theta_{3t} + \varepsilon_{3it} \quad (12)$$

3. Results and discussion

3.1 Results

In order to avoid the occurrence of spurious regression in the PVAR model, this study employed the LLC test, IPS, and Fisher-ADF tests to perform unit root tests on the variables of logistics competitiveness (LCN), logistics carbon emission efficiency (LCEE), and industrial structure upgrading (ISU), along with their first-order differences: dLCN, dLCEE, and dISU. The unit root test results for each variable or its difference value are shown in Tab. 2. According to Tab. 2, as LCN was not stationary in level, all variables have used the first difference in this study.

After the assessment of variable stability, the next step was to determine the optimal lag order for the PVAR model. This study used the Akaike information criterion (AIC), Bayesian information criterion (BIC), and Hannan-Quinn information criterion (HQIC) to evaluate the lag period. The results are presented in Tab. 3. According to Tab. 3, the criterion for determining the lag order is to select the one that yields the minimum value across all three criteria. Combining the subsequent analyses, the suitable lag period of the PVAR model is 2.

Tab. 2: Stationary tests

Variable	LLC	IPS	Fisher-ADF
LCN	−3.2036***	−3.5981***	58.4411
LCEE	−6.7915***	−5.2733***	128.0578***
ISU	−9.1172***	−2.1311**	129.0846***
dLCN	−5.8448***	−10.9297***	160.7649***
dLCEE	−8.4865***	−9.6844***	197.1394***
dISU	−5.3433***	−8.5483***	108.1009***

Note: *, **, *** denote significance at 10, 5 and 1% statistical levels; LCN – logistics competitiveness; LCEE – logistics carbon emission efficiency; ISU – industrial structure upgrading.

Source: own

In order to ensure the validity of GMM estimation, Granger causality test, impulse response analysis, and variance decomposition, it is necessary to examine the stability of the model. The results are presented in Fig. 1. Fig. 1 illustrates that all variables represented by points are within the circle, which shows that the PVAR model is stable.

Before estimating the PVAR model, this study applied forward mean-difference to eliminate fixed effects and time effects to reduce potential bias in estimating coefficients (Love & Zicchino, 2006). Then, the model was estimated using the generalized method of moment (GMM). The results are shown in Tab. 4.

Tab. 3: PVAR model lag period test

Lags	AIC	BIC	HQIC
1	−11.1933	−10.1246	−10.7684
2	−11.6853	−10.4420*	−11.1894*
3	−11.7103*	−10.2659	−11.1322
4	−11.5084	−9.8291	−10.8340
5	−11.2749	−9.3170	−10.4860

Note: * denotes the optimal order under this criterion.

Source: own

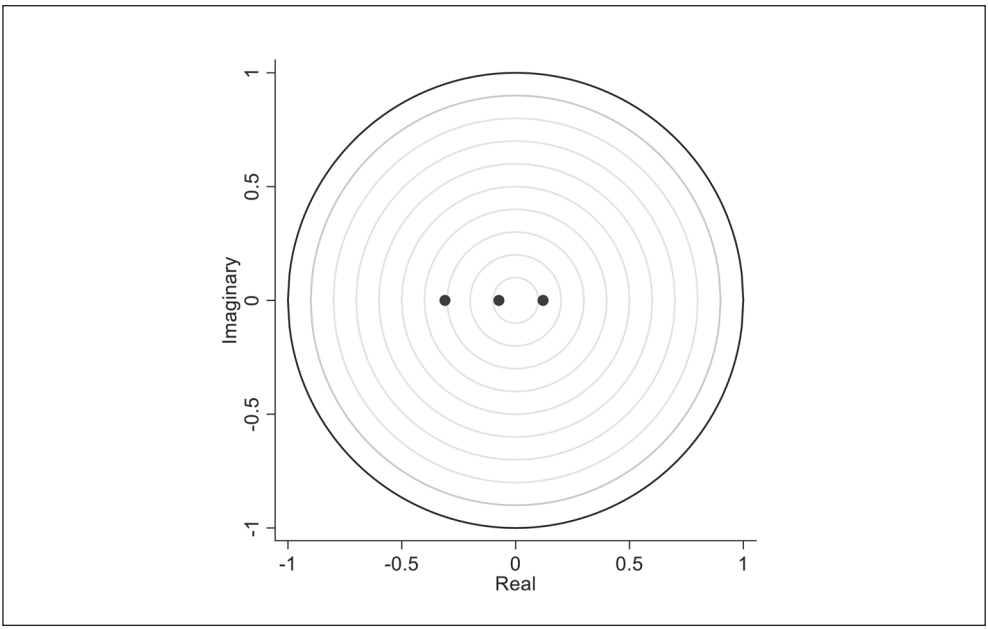

Fig. 1: Roots of companion matrix

Source: own

According to Tab. 4, h_dLCN, h_dLCEE, and h_dISU are the first order difference of variables that have eliminated time effects and fixed effects, and L1 and L2 represent lag order.

(1) Taking the h_dLCN as the explanatory variable, the estimated coefficient of LCEE is significantly negative, suggesting a reverse effect on LCEE within the lag period. The result is further supported by the work of Zhang et al. (2022a), where it is revealed that some inland regions of China, such as Ningxia, have a poorly developed logistics industry and lower carbon emissions. However, they can effectively utilise limited logistics resources to produce more economic benefits.

(2) Taking the h_dLCEE as the explanatory variable, the lagging LCN of phases I and II has a significant negative effect on the LCEE. The estimated coefficient of ISU is negative and not significant. This result is similar to that of Ding and Liu (2024), who suggested that the rapid expansion

of the tertiary sector inhibits the logistics industry carbon's efficiency.

(3) Taking the h_dISU as an explanatory, the first and second-order lag of logistics industry competitiveness and logistics carbon emission efficiency has a positive impact on the industrial structure upgrading. Our result is consistent with the finding of Liu et al. (2020), where enhancing regional logistics competitiveness and carbon emission efficiency of the logistics industry can drive the rapid development of the local tertiary industry and expedite the transformation of industrial structure.

The GMM estimation can only reflect the relationship between variables from a macro perspective and cannot specifically clarify the causal relationship between variables. Therefore, this study employed the Granger causality test, impulse response function, and variance decomposition in further analysis.

To explore the short-term dynamic causal relationships between variables, we applied the Granger causality test. The results are shown in Tab. 5. Dependent (equation) variables are represented on the horizontal axis, while excluded variables are represented on the vertical axis. According to Tab. 5, there is no two-way relationship between the three variables, while there is an unidirectional causal relationship from LCN to LCEE and ISU directions. Besides, a one-way causal relationship from LCEE to ISU is consistent with Tab. 4.

Tab. 4: GMM-PVAR results

Variable	Coefficient		
	h_dLCN	h_dLCEE	h_dISU
L1.h_dLCN	−0.3280	−1.0917**	0.8108***
L1.h_dLCEE	−0.0015	−0.0950	0.0690***
L1.h_dISU	0.0021	−0.0717	0.2408***
L2.h_dLCN	−0.0620	−1.5551***	0.6553***
L2.h_dLCEE	−0.0047**	−0.2688**	0.0401**
L2.h_dISU	0.0133	−0.0603	0.1871***

Note: *, **, *** denote significance at 10, 5 and 1% statistical levels; LCN – logistics competitiveness; LCEE – logistics carbon emission efficiency; ISU – industrial structure upgrading.

Source: own

Tab. 5: Granger causality results

Equation	Excluded	Chi²	df	Prob > chi²
LCN	LCEE	2.7987	2	0.247
	ISU	1.7647	2	0.414
	ALL	5.2292	4	0.265
LCEE	LCN	16.6180***	2	0.000
	ISU	0.6914	2	0.708
	ALL	33.7080***	4	0.002
ISU	LCN	36.4170***	2	0.000
	LCEE	6.1780**	2	0.046
	ALL	38.7990***	4	0.000

Note: *, **, *** denote significance at 10, 5 and 1% statistical levels; LCN – logistics competitiveness; LCEE – logistics carbon emission efficiency; ISU – industrial structure upgrading.

Source: own

The analysis of the impulse response function can evaluate the long-term dynamic impact between selected variables. Fig. 2 shows the impulse response function graph by using a Monte Carlo simulation with 200 runs over a time span of 1–10 periods. The horizontal axis represents the lag period, while the vertical axis represents the response degree of the explained variable; the red line in the middle is the impulse response function; and the other two lines represent the upper and lower limits of the 95% confidence interval.

According to Fig. 2, LCN, LCEE, and ISU experience significant negative impacts when facing a unit of standard deviation shock to themselves. Then, they are in a fluctuating state and tend to zero. There is a negative effect of LCN on LCEE, and it reaches the lowest point in period 1. Then, it shows an inverted U-shaped pattern, experiencing a quick increase in period 3 and finally declining to 0, which is similar to the impact of LCEE on LCN. When ISU affects LCN and LCEE, there is a positive effect in general and a peak in period 1. The result is contrary to the work of Jian et al. (2018) but similar to Chen and Zhang (2022). We find a long-term, stable, and dynamic relationship between logistics competitiveness and industrial structure upgrading. When ISU is shocked by LCEE and LCN, respectively, opposite results are observed. LCN has a positive impact on ISU and reaches its peak in period 2, followed by a slow regression to a steady state. On the contrary, LCEE has a negative impact on ISU and reaches the lowest point in period 2. Then, there is a growth trend, tending to 0.

The variance decomposition allows for the analysis of the percentage of variation in one variable that can be attributed to shocks in another variable across different observation periods. The results are shown in Tab. 6.

According to Tab. 6, all three variables have the highest contribution rates to themselves. The LCN variable describes itself at 98.8%, and ISU is affected by other variables. Compared to the ISU, LCN has a higher contribution to LCEE. It increases from 7% in the first period to 9.9% in the eighth period, while ISU only explains 0.2% of the changes in LCEE. In the variance decomposition of ISU, LCN has a greater impact than LCEE. It increases from 0.7% in the first period to 9.9% in the eighth

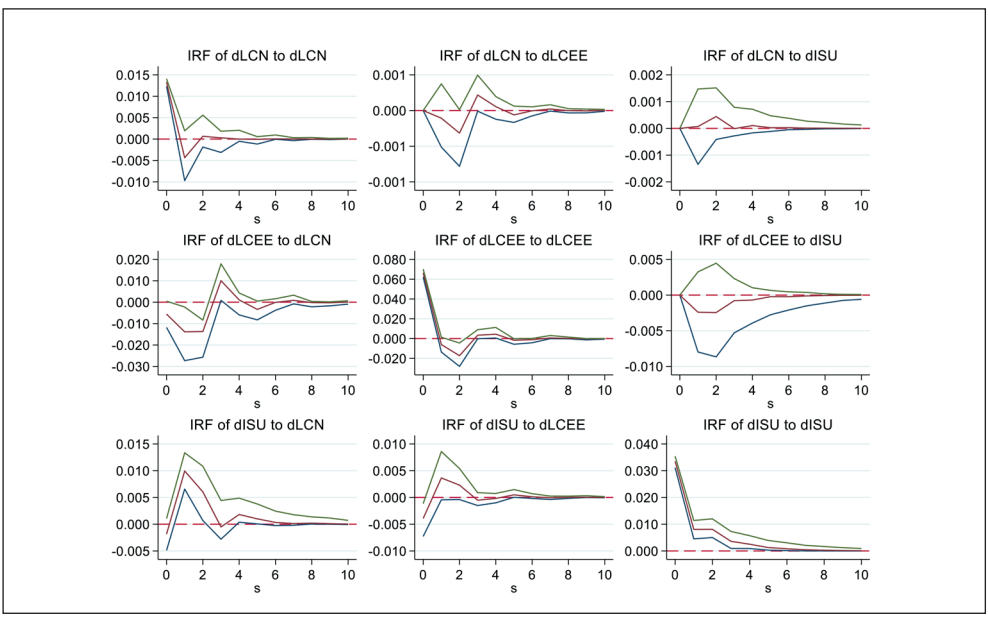

Fig. 2: **Impulse-response graph**

Source: own

Tab. 6: Variance decomposition results

Response	Impulse variable			
	Forecast horizon	dLCN	dLCEE	dISU
dLCN	1	1	0	0
	2	1	0	0
	3	0.998	0.001	0.001
	4	0.998	0.001	0.001
	5	0.998	0.001	0.001
	6	0.998	0.001	0.001
	7	0.998	0.001	0.001
	8	0.998	0.001	0.001
dLCEE	1	0.007	0.993	0.000
	2	0.047	0.951	0.001
	3	0.079	0.918	0.002
	4	0.097	0.901	0.002
	5	0.097	0.901	0.002
	6	0.098	0.899	0.002
	7	0.098	0.899	0.002
	8	0.099	0.899	0.002
dISU	1	0.003	0.014	0.983
	2	0.078	0.022	0.901
	3	0.097	0.024	0.879
	4	0.097	0.024	0.879
	5	0.098	0.024	0.878
	6	0.098	0.024	0.877
	7	0.098	0.024	0.877
	8	0.099	0.024	0.877

Source: own

period. This indicates that regional logistics competitiveness has a significant driving effect on logistics carbon emission efficiency and industrial structure upgrading.

3.2 Discussion

By constructing a PVAR model and using impulse response, this study finds that logistics competitiveness has a U-shaped effect on logistics carbon emission efficiency. Furthermore, it shows a negative effect in the short term and a positive effect in the long term, with fixed time lags, confirming the environmental Kuznets curve. The obtained results align with the findings of other scholars (Zaman & Shamsuddin, 2017). We all find that logistics competitiveness will promote carbon emissions in the early stages and result in lower carbon emission efficiency. However, once competitiveness reaches a certain level, it will improve carbon emission efficiency, conversely. The explanation is that the initial development of China's logistics industry adopted an extensive development model (Pan et al., 2020).

As the logistics industry expands, it consumes a significant amount of energy and generates substantial carbon dioxide emissions in transportation, warehousing, distribution, and other processes (Quan et al., 2020). Nevertheless, the carbon emission efficiency is relatively low due to the industry being in its earlier stage with lower socioeconomic contributions. As the logistics industry has grown into the pillar industry of China, this extensive development mode has led to rapid economic growth and technological innovation. By implementing green logistics policies and optimizing energy consumption, an effective energy conservation and emission reduction system has been established, which reduces energy consumption and carbon emissions (Xiao et al., 2015). Finally, this results in an upward trend in the efficiency of the logistics industry's carbon emissions.

From the perspective of industrial structure upgrading, it is the main driving factor in logistics competitiveness and has a long-term dynamic impact. This is consistent with the view of Chen and Zhang (2022). They pointed out that upgrading the industrial structure was closely related to the high-quality development of regional logistics in China. The boom of e-commerce has been driven by the tertiary industry, leading to an increase in consumption levels and customised needs among inhabitants (Adil et al., 2022), This, in turn, has made consumers more reliant on logistics services. As a result, there is a growing demand for logistics services, and enterprises are continuously striving to improve their service levels, enhance delivery efficiency, and promote the high-quality development of logistics. Zhou and Li (2022) concluded that industrial structure had a positive but insignificant impact on logistics competitiveness. However, this result might be attributed to the limited scope of their research, which only included provinces in western inland China with relatively simple industrial structures.

Industrial structure upgrading has a significant positive impact on logistics carbon emission efficiency. The industrial transformation involves shifting labor-intensive industries, mainly based on agriculture and traditional handicrafts, towards more technologically advanced manufacturing, modern services, and the digital economy industry (Yan et al., 2023). According to Zhou et al. (2021), the advanced industrial structure was conducive to reducing environmental pollution. As the largest developing country, China should focus on optimising its industrial structure to reduce carbon emissions (Sikder et al., 2022). The industrial structure can significantly affect energy consumption, and the proportion of primary, secondary, and tertiary industries directly influences the consumption of energy (Xiao et al., 2015). Compared to the primary and secondary industries, the rapid development of the tertiary industry has stimulated greater logistics demand for enterprises (Zhou et al., 2022), which has led to the adoption of various measures, such as optimizing transportation routes and utilizing low-carbon technologies (Li & Wang, 2022) and green energy to improve logistics efficiency (Wang & Dong, 2023). These actions not only significantly reduce carbon emissions but also improve economic and social benefits, thereby enhancing carbon emission efficiency.

In addition, the upgrading of industrial structure will result in the substitution of conventional industries with advanced technological companies, while the local government will increasingly enforce stringent environmental regulations. Traditional industrial enterprises, reliant on fossil fuels, relocate to areas with lax environmental policies. This behaviour will reduce carbon emissions and improve carbon emission efficiency, consistent with the "pollution haven" hypothesis.

Conclusions

This paper is based on the provincial panel data of China from 2007 to 2021 to construct a PVAR model to study the dynamic relationship between logistics competitiveness, logistic carbon emission efficiency, and industrial structure upgrading. The specific conclusions are as follows: i) the logistics competitiveness, logistic carbon emission efficiency, and industrial structure upgrading in each province and autonomous region all have self-adjustment effects; ii) a U-shaped effect is observed from the effect of logistics competitiveness on logistics carbon emission efficiency, which shows a negative impact in the short term and a positive impact in the long term. It is the same as the effect of logistics carbon emission efficiency on logistics competitiveness, indicating the existence of the time-lag effect; and iii) industrial structure upgrading has a positive promotion effect on logistics industry competitiveness and logistics carbon emission efficiency.

Based on the aforementioned research conclusions, this study proposes the following three suggestions: i) strengthen the infrastructure for the modern logistics system. A vast logistics service network relies on excellent professionals and sound infrastructure. The government should improve the layout of the logistics industry infrastructure, accelerate the construction of the industrial system, and build integrated transport hubs, which can increase the transportation efficiency of the system. Especially in backward areas, it is necessary to attract college graduates back to their hometowns for employment through subsidies or preferential policies; ii) enhance the carbon emission efficiency of the logistics industry. Although the initial stage of enhancing carbon emission efficiency in the logistics industry may have adverse effects on regional logistics competitiveness, in the long run, continuous optimisation and adjustment of the economic structure can lead to high-quality development in the logistics industry. On the one hand, the government and enterprises can vigorously promote clean energy and reconfigure energy consumption patterns to build an inclusive green economy. On the other hand, developed regions can leverage their regional advantages, increase research and development efforts, and use green and high-tech innovations to support energy-exporting provinces, replacing high-carbon and low-efficiency with low-carbon and high-efficiency; and iii) accelerate the adjustment of the industrial structure. The logistics industry has a wide range of business scopes, including production, storage, transportation, consumption, and other aspects. The increase in the proportion of the tertiary industry can greatly stimulate economic growth, accelerate the circulation of factors between industries, and significantly promote the high-quality development of the logistics industry. In this regard, the government needs to play a leading role, provide support and subsidies to relevant enterprises, stimulate the development of the tertiary industry, optimise the industrial structure, and achieve optimal allocation of resources.

There are several limitations that need to be addressed in future research. First, the selection of indicators for variables in this study has certain limitations. Future research could employ different methods for indicator selection. Second, the findings of this study are specific to China. Future research could expand on this by dividing China into several regions to explore the intrinsic relationship between logistics competitiveness, logistics carbon emission efficiency, and industrial structure or study other countries.

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Navigating the Industry 4.0 frontier: Unveiling perceived risk and cost moderators in technology adoption

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Abstract: *The advent of Industry 4.0 (I4.0) brought about significant transformations within the realm of business management. Industries are increasingly adopting innovative practices and implementing smart supply chain operations through the adoption of I4.0 technologies. Therefore, this study aims to investigate the factors that influence the adoption of I4.0 in supply chain operations. To accomplish this, an extended unified theory of acceptance and use of technology (UTAUT) model was applied, with perceived risk and cost acting as moderators in the context of the manufacturing sector. The study used a quantitative research methodology, with a sample size of 276 participants who held managerial positions at various levels within the sector. The data were obtained through the use of a structured questionnaire employing a judgmental sampling technique. The findings of the study revealed that both social influence and facilitating conditions had a significant impact on the adoption of I4.0. However, the relationship between social influence and I4.0 adoption was only moderated by perceived risk and cost. The aforementioned findings indicate that it is imperative that firms give precedence to the establishment of a conducive environment and culture that nurture innovation and promote the assimilation of cutting-edge technologies. Furthermore, it is essential for individuals to prioritize the establishment of strong networks and collaborations in order to effectively leverage the advantages offered by the I4.0. The implications of this study offer valuable insights for policymakers, practitioners, and researchers in the field of I4.0 and technology adoption. These insights pertain to the significant factors that influence the decision to adopt I4.0 and the anticipated applications of I4.0 within the supply chain.*

Keywords: *Industry 4.0, technology adoption, UTAUT, manufacturing firms, SDG17.*

JEL Classification: *M11, M15, L60.*

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Introduction

Industry 4.0, also known as I4.0, is a modern manufacturing strategy that involves the implementation of digital and interconnected industrial value generation models (Senna et al., 2022; Tortorella & Fettermann, 2018). There are multiple benefits associated with this strategy, such as enhanced utilization of resources, increased levels of personalization, and the emergence of novel business models

(Senna et al., 2022). As I4.0 takes hold, disruptive technologies such as blockchain, big data, and the internet of things (IoT) are transforming multiple supply chain components (Jum'a et al., 2022; Khan et al., 2022). Logistics is an essential part of supply chain management, and the success of I4.0 is dependent on its digital transformation in logistics operations. In this context, the current logistics system must be modernized with I4.0 technology in order to become logistics 4.0 (Khan et al., 2022). There is currently little knowledge on how these technologies may be used in enterprises' established production facilities and what the benefits are to firms making an informed decision to transition to I4.0 (Kumar et al., 2022). Many firms are hesitant to adopt I4.0 because they do not completely understand the potential changes to their operations and organizational structure (Hamada, 2019).

Despite the fact that I4.0 is associated with the aforementioned benefits, many studies have shown variances in adoption intensity and scale (Hamada, 2019; Kumar et al., 2022; Tortorella & Fettermann, 2018). Previous studies in the field of technology management have shown similar findings, indicating that different technologies have similar patterns. The adoption of technology by businesses is influenced by a variety of factors (Jum'a et al., 2022; Senna et al., 2022; Shi et al., 2022). For example, Khin and Kee (2022) demonstrated that knowing the vital elements to consider might help manufacturing companies decide whether to engage in I4.0. Decision-makers are more likely to be driven to take action if they are convinced of the benefits rather than deterred by the drawbacks. As a result, understanding the advantages and disadvantages of I4.0 will enable them to weigh the benefits and drawbacks of adopting it. According to Narula et al. (2020), the fact that many organizations are not even familiar with the critical aspects driving I4.0 adoption is still troubling, even though businesses are aware of its potential. This has resulted in a slow and unequal speed of change across industries, regardless of the country of origin. Emerging and developing markets face distinct challenges when it comes to investing in I4.0. For example, Tortorella et al. (2019) highlighted several notable initiatives undertaken by various countries to embrace I4.0. The Mexican Ministry of Economy has presented a comprehensive framework outlining the steps required for the adoption of I4.0 in Mexico. Similarly, the Brazilian National Confederation of Industry has identified and documented the existing challenges and obstacles hindering the successful implementation of I4.0 in Brazil. Furthermore, the Indian Government has introduced a strategic plan aimed at positioning the country as a prominent global production hub in the context of I4.0 (Tortorella et al., 2019). Moreover, the COVID-19 pandemic has exerted significant pressure on developing and emerging countries to devise a digital computing infrastructure capable of remote operation, thereby reducing the need for in-person human interaction (Khin & Kee, 2022). In light of these challenges, manufacturers are actively seeking more flexible and efficient operational protocols, made possible by advanced digital technologies commonly referred to as I4.0 or smart manufacturing (Khin & Kee, 2022). According to Kumar Bhardwaj et al. (2021) and Jum'a (2023), the integration of blockchain technology within the supply chains of small and medium-sized enterprises (SMEs) is expected to enhance operational processes, overall performance, and efficiency. The adoption of I4.0 is contingent upon the mindset of influential decision-makers within organizations, as these individuals are inclined to embrace risk-taking and make substantial investments in future endeavors when their companies demonstrate successful performance (Kumar et al., 2022). Decision-makers who have a strong preference for innovation and are prepared to accept the risks involved in adopting novel information systems can facilitate the successful implementation of I4.0 (Hamada, 2019). Despite the numerous benefits associated with I4.0, several studies have identified disparities in the level of adoption (Kijsanayotin et al., 2009; Senna et al., 2022).

The investigation of adoption intention towards I4.0 can be conducted using various acceptance models. For instance, the study of Puriwat and Tripopsakul (2021) confirmed what the unified theory of acceptance and use of technology (UTAUT) model said about the relationships between performance expectancy (PE), effort expectancy (EE), social influence (SI), facilitating conditions (FC) and the intention to use information technology, as well as the direction of those relationships. Another model is the TOE framework that incorporates adoption variables that are intrinsic to the adopting organization, including factors such as the size of the firm, managerial

support, and the ability to recognize the value of new information, assimilate it, and utilize it to achieve business objectives (Senna et al., 2022). However, the UTAUT is a prevalent theoretical framework employed to elucidate the factors influencing the adoption of emerging technologies. According to Venkatesh et al. (2003), the UTAUT model proposes that there are four constructs, namely PE, EE, SI, and FC, which directly influence both behavioral intention and behavior. The UTAUT has garnered substantial empirical support from a wide range of studies (Afifa et al., 2022; Hewavitharana et al., 2021; Pieters et al., 2022). Furthermore, this model has the potential to yield intriguing findings. The UTAUT model provides a more rational framework for examining the process of technology adoption. The captured aspects include the alignment between technology and task requirements, the impact on society, and the availability of resources as facilitating conditions (Dissanayake et al., 2022). In comparison to other models and theories, this particular model demonstrates a superior level of explanatory power (Dissanayake et al., 2022).

As demonstrated by Khin and Kee (2022), multiple research investigations have yielded findings suggesting that the presence of FC, such as governmental support, may accelerate the process of technology adoption. Hence, the present study endeavors to expand upon the UTAUT model and tackle its limitations by examining the other key factors, namely perceived cost and risk, that may impact the adoption of I4.0. In summary, the objective of this study was to employ the extended UTAUT model in order to simulate individuals' inclination to adopt I4.0 technologies, with perceived cost (PC) and perceived risk (PR) serving as moderating factors. Therefore, this study addresses the existing knowledge gap regarding the human aspect of digitalization in the manufacturing industry based on an extended UTAUT framework. The rationale for employing the UTAUT framework in this study stems from its recognized comprehensiveness in evaluating individual-level technology acceptance (Afifa et al., 2022; Tusyanah et al., 2021). It serves as a foundation for identifying and resolving the challenges that have arisen during the process of digital transformation within the industry. Moreover, the research has developed an expanded framework that can be effectively utilized to methodically incorporate the human factor into the process of digitally transforming I4.0. Furthermore, this facilitates the examination of evolving human requirements in digitally altered settings, such as I4.0 environments, and contributes to a prosperous digital transformation that circumvents the drawbacks of innovation conducted without consideration for human factors (Hewavitharana et al., 2021; Puriwat & Tripopsakul, 2021).

The literature reviews of previous, relevant research are included in the literature review section, as is a table with a summary of the findings from earlier studies on how I4.0 is helping supply chain management. Following that, the conceptual model and hypotheses are presented. The methodology of the investigation is then presented. The study's findings are also provided. The appropriate theoretical and managerial implications and conclusions are then used to get the result.

1. Theoretical background

1.1 UTAUT model and adoption of I4.0

In the contemporary digital era, a multitude of advanced communication systems, such as blockchain, the IoT, and cloud computing, have emerged (Veile et al., 2020). These systems have been designed to provide extensive capabilities across various applications and scenarios (Kumar Bhardwaj et al., 2021). Insufficient understanding of the societal and technical aspects of information technology, specifically the integration of digital technologies by individuals and organizations, is a significant contributing factor to failures (Dissanayake et al., 2022; Pieters et al., 2022; Puriwat & Tripopsakul, 2021). Manufacturing companies frequently exhibit a sense of prudence when it comes to embracing I4.0 for the purpose of digitally transforming their operational procedures. Despite the various benefits I4.0 presents and its increasing significance within the realm of supply chain management, there are various additional factors that need to be considered prior to allocating funds for its costly implementation (Khin & Kee, 2022). The UTAUT model shows an approach that is more effective than previous models (Afifa et al., 2022; Dissanayake et al., 2022; Pieters et al., 2022) at finding the factors that cause differences in IT behavioral intention and use behavior.

Puriwat and Tripopsakul (2021) conducted a study applying the UTAUT model to assess individuals' intentions and actual usage

of social media platforms. The findings of this study indicate that PE and EE, as well as SI, have a significant impact on the likelihood of adopting social media for business purposes. The presence of FC significantly influenced the actions taken by users. Another study was conducted by Pieters et al. (2022) with the aim of obtaining insights into the adoption of blockchain technology. In the organizational context, hedonic motivation proved to be a significant factor that influences the adoption of blockchain technology. PE, SI, and FC emerged as significant predictors for adoption. The lack of EE significance indicates that the perceived complexity of blockchain technology does not discourage potential users.

Moreover, the research conducted by Afifa et al. (2022) employed the UTAUT model, incorporating several external factors. The findings of the study indicate that both PE and EE positively impact the intention to adopt blockchain technology. However, it was observed that SI has a comparatively weaker influence on the intention to use blockchain. Furthermore, it is worth noting that trust plays a significant role in influencing both PE and EE, as well as the intention to utilize blockchain technology. The lack of correlation between the intention to utilize blockchain technology and compatibility adds to its inherent intrigue. In an empirical study, Hamada (2019) sought to determine the factors influencing decision-makers' perceptions of the adoption of I4.0. The study utilized data obtained from a sample of Japanese manufacturers. The results suggest that there is no significant association between the adoption of I4.0 by enterprises and the company's size. In addition, decision-makers who hold the belief that their company is achieving satisfactory performance tend to hold positive opinions regarding the adoption of I4.0. Encouraging decision-makers to develop a positive attitude towards the adoption of I4.0, enhancing their adoption of relevant information, and addressing any deficiencies in capabilities can serve as catalysts for promoting adoption.

In their study, Kijsanayotin et al. (2009) employed a modified UTAUT model to examine the factors influencing the acceptance of health information technology (IT) in community clinics in Thailand. The aim was to validate the applicability of the existing IT adoption model within the healthcare context of a developing nation. The results of the study revealed that the inclination to utilize health information technology (IT) is contingent upon various factors. These factors encompass the belief that health IT will be advantageous in terms of performance (PE), the belief that it will be uncomplicated to operate (EE), the belief that influential individuals will endorse the use of health IT (SI), and the belief that individuals have the freedom to decide how to employ IT (voluntariness). The aforementioned four variables exhibited a significant level of predictive capacity and accounted for more than 50% of the variability in the intention to use information technology. The most influential predictor among these four contributing factors was PE. In a recent study conducted by Ronaghi and Forouharfar (2020), the primary objective was to ascertain the key factors that contribute to the adoption and subsequent implementation of IoT technology in the context of smart farming. The findings of the study highlighted and confirmed the significant effects of PE, EE, SI, FC, and individual factors on the intention to adopt IoT technology. Finally, the study by Tusyanah et al. (2021) identified a number of factors that influence behavioral intention, including EE, PE, SI, and FC. The study also revealed that an individual's level of experience moderates the relationship between EE and intention. In their study, Hewavitharana et al. (2021) identified PE as the primary driving force behind individuals' inclination towards digital transformation using the analytical hierarchy process approach. Finally, a study by Kwarteng et al. (2023) employed an extended UTAUT framework as the basis for a research model examining the factors influencing the adoption of digitalization in European SMEs. The model incorporates PE, EE, FC, and competitive pressure as potential influential factors. All of the aforementioned factors were found to have a significant impact on the digitalization of SMEs, with the exception of EE.

1.2 Influence of UTAUT factors on I4.0 adoption

The fundamental UTAUT model comprises various components or constructs that are hypothesized to be associated with the intention to adopt information technology, including expected performance, expected effort, social impact, and FC (Pieters et al., 2022; Puriwat & Tripopsakul, 2021). These components play a significant role in the decision-making

process regarding the adoption of technology. In the study conducted by Hamada (2019), significant and positive results were observed in relation to the impact of "Performance" on the adaptation of the company to I4.0. In a study conducted by Kijsanayotin et al. (2009), it was found that several factors play a significant role in determining an individual's likelihood of adopting health IT. These factors include the perceived usefulness of health IT, the perceived ease of use, the SI exerted by important individuals in one's life, and the perception of personal autonomy in the decision to use IT. The explanatory power of these four variables was found to account for over 50% of the variance in the intention to utilize information technology, indicating a robust predictive ability. According to Khin and Kee (2022), the facilitation of digital transition can be supported by academic institutions through their assistance in developing the requisite technologies or solutions. Business enterprises could potentially achieve cost savings by collaborating with academic institutions, thereby obviating the need for direct acquisition of requisite solutions. The adoption of I4.0 is subject to notable influences stemming from technological, organizational, and environmental factors. The adoption of I4.0 is positively influenced by factors such as relative advantage, senior management support, and competitiveness. In their study, Kwarteng et al. (2023) observed that the two components of the UTAUT model, namely PE and FC, exert a substantial influence on the digitalization efforts of companies. The subsequent hypotheses have been formulated.

H1: PE positively influences I4.0 adoption.
H2: EE positively influences I4.0 adoption.
H3: SI positively influences I4.0 adoption.
H4: FC positively influences I4.0 adoption.

1.3 Moderating role of perceived cost

The decision for embracing new technology is influenced by two key cost elements: perceived costs and cost reductions (Salim, 2022; Shi et al., 2022). These two cost factors exhibit contrasting effects on the inclination to utilize. As shown by Salim (2022), there is a negative correlation between the desire to adopt a technology and the perceived financial burden associated with its implementation. According to Chulkov's (2017) findings, the permanence or reversibility of the decision to adopt a technology is contingent upon the level of efficiency in managing switching costs. According to Schmidthuber et al. (2020), the permanence of technology adoption is contingent upon the presence of high costs associated with transitioning from one IT solution to another. Moreover, Salim (2022) suggested that the PC does not function as a mediator, but rather as a moderator in the relationship between the enablers and inhibitors of the technology readiness index (TRI) and the desire for embracing blockchain technology. Finally, according to the findings of Rahi and Ghani (2016), it can be inferred that consumer perceived value and the moderating factor of switching cost exert a substantial influence on customer loyalty within the online banking domain of the banking sector. Consequently, the following hypotheses have been formulated.

H5a: PC moderates the relationship between PE and I4.0 adoption.

H5b: PC moderates the relationship between EE and I4.0 adoption.

H5c: PC moderates the relationship between SI and I4.0 adoption.

H5d: PC moderates the relationship between FC and I4.0 adoption.

1.4 Moderating role of perceived risk

There are numerous risks associated with the adoption of novel technologies. PR encompasses various dimensions, including monetary, security, mental, emotional, time, and performance risks (Suroso et al., 2022). The acceptance of technology by industries and companies can be facilitated by minimizing the PRs through the pursuit of excellence in performance, the application of minimal effort, the influence of societal factors, and the presence of favorable circumstances (Khin & Kee, 2022; Kumar Bhardwaj et al., 2021; Senna et al., 2022). Hence, Jangir et al. (2022) discovered a statistically significant positive relationship between individuals' intention to persist in utilizing FinTech services and their perceptions of utility, contentment, and confirmation. The findings of this study reveal that the PR factor plays a moderating role in the relationship between satisfaction and both continuation intention and confirmation of contentment. Nevertheless, their findings also indicated that the influence of PR on the relationships between perceived value and the intention to sustain technology usage was minimal. In the study conducted by Im et al. (2008), it was found that PR plays

a significant moderating role in the relationship between different variables and the intention to use technology. The results highlight the importance of including PR as a critical element in the UTAUT model. In order to investigate the moderating effect of PR on the relationship between UTAUT elements and the intention to adopt I4.0, following hypotheses have been formulated.

H6a: PR moderates the relationship between PE and I4.0 adoption.

H6b: PR moderates the relationship between EE and I4.0 adoption.

H6c: PR moderates the relationship between SI and I4.0 adoption.

H6d: PR moderates the relationship between FC and I4.0 adoption.

The conceptual model is shown in Fig 1.

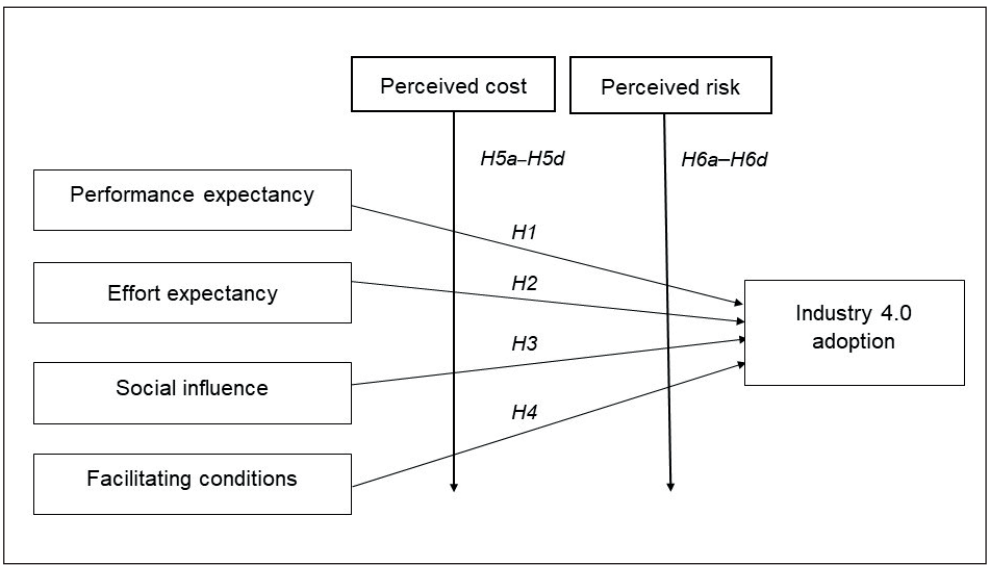

Fig. 1: The conceptual model

Source: own

2. Research methodology

2.1 Sampling procedures

This study focused on manufacturing companies in Jordan, specifically Amman. The individual manufacturing company served as the unit of analysis. To choose participants, the researchers utilized a judgmental sampling technique under non-probability sampling methods due to cost and time constraints. However, Malhotra (2010) shows that this method can still offer reliable estimations of population characteristics. The researchers used a structured questionnaire and a quantitative survey approach to collect data, which allowed for the objective evaluation of variable connections and the generalization of findings to a larger audience. A sample size of 200 or more was selected based on previous research recommendations (Hair et al., 2019), and the questionnaire was completed online by 276 respondents between March and June 2023. The information was cleaned and evaluated using proper statistical data analysis techniques.

2.2 Questionnaire measurement items

The measurement items used throughout this study were selected from relevant previous studies. The constructs of PE, EE, SI, and FC were derived from the studies of Puriwat and Tripopsakul (2021) and Pieters et al. (2022). The items pertaining to PC were derived from Lin et al. (2016), while the items concerning

PR were sourced from Im et al. (2008). Tortorella et al. (2019) conducted a study in which they adopted the items pertaining to the adoption of I4.0. The survey was structured into two sections, with the initial section encompassing demographic information and the subsequent section comprising measurement items. Participants were instructed to assess their level of agreement and disagreement about I4.0 in the context of supply chain operations using a five-point Likert scale, which ranged from 1 (indicating strong disagreement) to 5 (indicating strong agreement) as shown in Appendix 1.

2.3 Profile of the respondents

Gender, age, years of experience, education level, position, number of employees, and firm type were all demographic characteristics used in the study. The findings revealed that the majority of participants (91.7%) were male and between the ages of 31 and 40 (45.7%). The majority of participants (39.5%) had 5–10 years of experience and (81.9%) had a Bachelor's degree. The majority of participants (72.8%) were in first-line management positions and worked in companies with 20–99 employees (59.1%). Food and supply (34.1%) had the most enterprises represented,

Tab. 1: Demographic profile of the respondents

Category	Subcategory	Frequency (*n*)	Percent (%)
Gender	Male	253	91.7
	Female	23	8.3
Age (years)	21–30	73	26.4
	31–40	126	45.7
	41–50	45	16.3
	Above 50	32	11.6
Years of experience	Less than 5	74	26.8
	5–10	109	39.5
	More than 10	93	33.7
Education level	Diploma degree	8	2.9
	Bachelor degree	226	81.9
	Master's degree and above	42	15.2
Position	First line managers	201	72.8
	Middle managers	48	17.4
	Top managers	27	9.8
Number of employees	Less than 20	23	8.3
	20–99	163	59.1
	100 and more	90	32.6
Type of firm	Printing and paper	33	12.0
	Therapeutics	30	10.9
	Chemicals	50	18.1
	Plastic products	69	25.0
	Food and supply	94	34.1

Source: own

followed by plastic products (25.0%), chemicals (18.1%), printing and paper (12.0%), and therapeutics (10.9%) as shown in Tab. 1.

3. Results and discussion

3.1 Results

The means and standard deviations for several constructs connected to I4.0 adoption are provided by this descriptive analysis. In terms of mean, the PC had the highest value (M = 4.25, SD = 0.985), followed by FC (M = 4.08, SD = 0.886) and PR (M = 4.07, SD = 0.878). EE had the lowest mean (M = 2.41, SD = 1.008) of all the constructs as illustrated in Tab. 2. Overall, these findings imply that while EE may be a barrier to adoption, PC and FC may be significant factors influencing I4.0 adoption.

Tab. 2: Descriptive statistics (*N* = 276)

Constructs	Mean	Std. deviation	Skewness	Std. error	Kurtosis	Std. error
PE	3.53	1.261	−0.921	0.147	−0.567	0.292
EE	2.41	1.008	0.963	0.147	−0.124	0.292
SI	3.95	0.872	−1.672	0.147	3.344	0.292
FC	4.08	0.886	−2.156	0.147	4.063	0.292
PC	4.25	0.985	−1.983	0.147	2.877	0.292
PR	4.07	0.878	−1.387	0.147	2.440	0.292
I4.0 adoption	3.75	0.965	−1.616	0.147	2.004	0.292

Source: own

Tab. 3: Multicollinearity test

Latent variables	Collinearity statistics	
	Tolerance	VIF
PE	0.889	1.125
EE	0.978	1.022
SI	0.924	1.082
FC	0.857	1.166

Source: own

The estimated path coefficients may be impacted by the presence of multicollinearity among the independent variables. To identify multicollinearity, the researchers calculated the tolerance values and variance inflation factor (VIF). The results indicated that there was no multicollinearity among the independent variables since all the VIF values were less than 5 and the tolerance values were above 0.10 (Hair et al., 2019). Tab. 3 provides further details on these findings.

SmartPLS version 3 was utilized for performing the structural equation modelling (Ringle et al., 2015). There were two phases including measurement model analysis and structural model analysis.

Constructs' reliability was assessed with the values of Cronbach's alpha and composite reliability. The results showed that all the values were above the recommended level (>0.70) and thus acceptable (Hair et al. 2019). Moreover, a convergent validity assessment was performed with the values of factor loading above 0.70 and average variance extracted (AVE) values above 0.50. The results indicated that all the values of factor loading and AVE fall under the recommended level (Hair et al. 2019) as shown in Tab. 4.

To achieve discriminant validity, all the square root values of AVE should be higher than the correlation coefficients between the particular constructs (Fornell & Larcker,

Tab. 4: Construct reliability and validity

Constructs	Items	Factor loadings	Cronbach's alpha	Composite reliability	AVE
I4.0 adoption	ADOP.INT1	0.932	0.981	0.983	0.856
	ADOP.INT2	0.927			
	ADOP.INT3	0.929			
	ADOP.INT4	0.951			
	ADOP.INT5	0.937			
	ADOP.INT6	0.911			
	ADOP.INT7	0.937			
	ADOP.INT8	0.918			
	ADOP.INT9	0.905			
	ADOP.INT10	0.902			
EE	E.EX1	0.999	0.943	0.951	0.869
	E.EX2	0.999			
	E.EX3	0.780			
FC	F.CON1	0.924	0.950	0.962	0.835
	F.CON2	0.923			
	F.CON3	0.922			
	F.CON4	0.916			
	F.CON5	0.882			
PC	P.COST1	0.944	0.938	0.960	0.890
	P.COST2	0.943			
	P.COST3	0.943			
PE	P.EX1	0.977	0.973	0.980	0.925
	P.EX2	0.954			
	P.EX3	0.941			
	P.EX4	0.973			
PR	P.RK1	0.953	0.966	0.975	0.907
	P.RK2	0.925			
	P.RK3	0.970			
	P.RK4	0.959			
SI	S.INF1	0.956	0.934	0.957	0.882
	S.INF2	0.923			
	S.INF3	0.939			

Source: own

Tab. 5: Discriminant validity

Constructs	1.	2.	3.	4.	5.	6.	7.
1. EE	0.932						
2. FC	0.060	0.914					
3. I4.0 adoption	0.104	0.488	0.925				
4. PC	0.070	0.589	0.528	0.943			
5. PR	0.079	0.445	0.344	0.408	0.952		
6. PE	0.096	0.317	0.231	0.301	0.141	0.962	
7. SI	0.120	0.247	0.264	0.291	0.375	0.140	0.939

Source: own

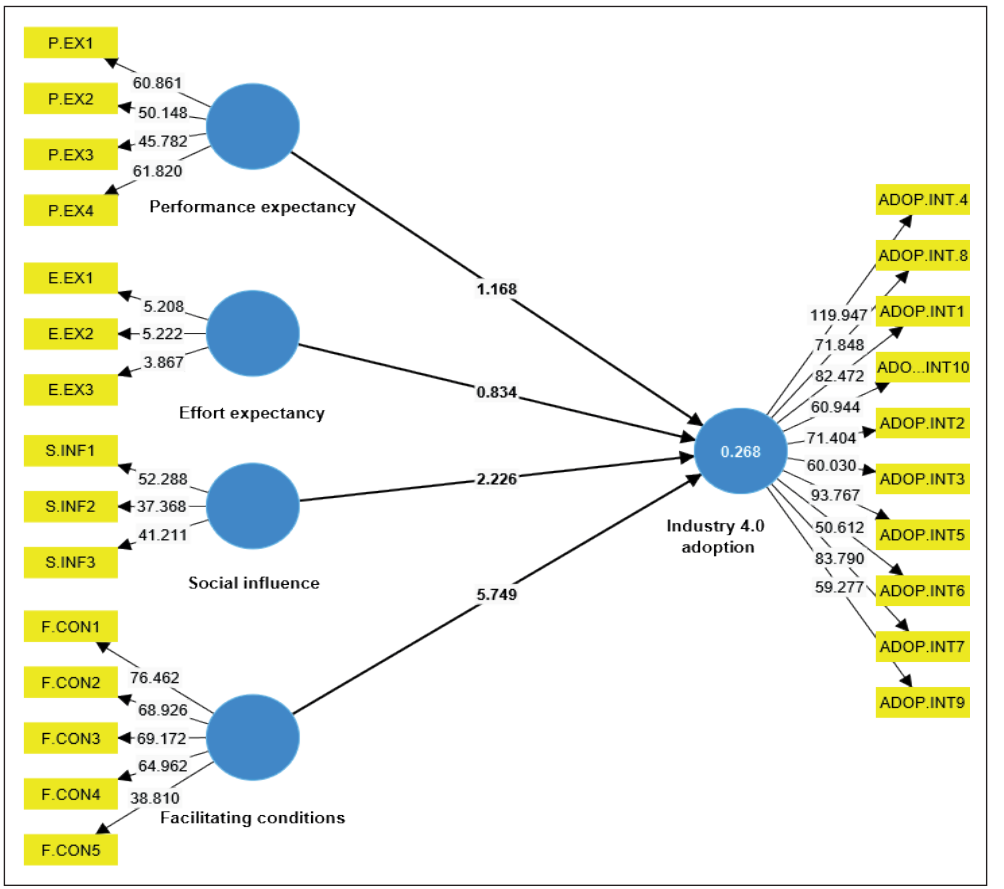

Fig. 2: Structural model diagram 1

Source: own

1981). The results suggested that the study's constructs had sufficient discriminant validity as the square root values of AVE were greater than the inter-construct correlations, as shown in Tab. 5.

After confirming the accuracy of the measurement model, as stated by Hair et al. (2019), the structural model is then evaluated to test the hypotheses proposed in the theory. In this particular study, the structural model was estimated using a bootstrapping method with a subsample of 1,000, as indicated by Ringle et al. (2015). The model explained a 34.2% variation in I4.0 adoption as indicated by the value of *r*-square as shown in Fig. 2.

The fitness of the model was evaluated using SRMR (0.032) and NFI (0.861) values, and it was found that the SRMR value was less than 0.09, and the NFI value was close *t* 0.90, which suggests that the model's fitness was adequate according to Byrne's (2013) standards. Fig. 3 shows structural model with the two moderator variables to test the hypotheses proposed in the extended UTAUT model.

According to Byrne (2013), a *t*-value in a two-tailed test is considered statistically significant if it falls outside the range of −1.96 to +1.96, and if the *p*-value is less than 0.05. Tab. 6 presents the results of a structural model test, which includes path coefficients (β), *t* statistics, and *p*-values. The direct effects of the model indicate that the two hypotheses were significant at a *p*-value less than 0.05. This means that SI and FC significantly influenced I4.0 adoption. Therefore, hypotheses *H3*, *H4*, *H5c*, and *H6c* were supported and significant, while other hypotheses were not supported and were insignificant.

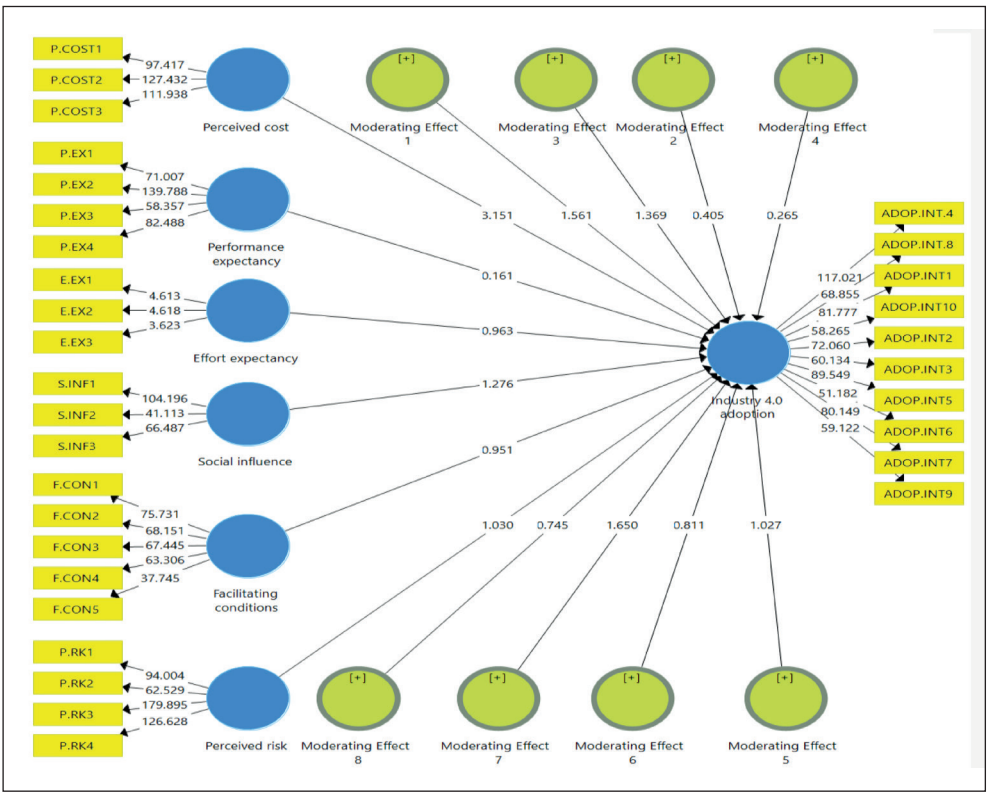

Fig. 3: Structural model diagram 2

Source: own

3.2 Discussion

The purpose of this study was to investigate the adoption of I4.0 technology by manufacturing firms, specifically in relation to supply chain operations. The study employed an extended UTAUT framework to analyze the factors influencing the adoption process. In recent years, a number of studies have endeavored to establish a connection between I4.0 technology and various aspects of manufacturing, supply chain management, and related domains (Khin & Kee, 2022). The study focused on the development of a model based on UTAUT, while also examining the moderating effects of PR and cost. The findings were consistent with certain previous studies, although there were discrepancies observed in certain outcomes.

Initially, it should be noted that despite the existence of certain studies that have observed a potential relationship between PE and the triggering or downturn of I4.0 technology (Catherine et al., 2017; Zeqiri et al., 2021), the evidence suggests that PE alone is not sufficient to elicit such effects. The degree to which employees express a desire to embrace a particular technology is significantly impacted by their perception of the technology's capability

Tab. 6: Results of the structural model

	Beta	*t*-statistics	*p*-values	Results
Paths				
PE → I4.0 adoption	0.070	1.168	0.243	Rejected
EE → I4.0 adoption	0.055	0.834	0.404	Rejected
SI → I4.0 adoption	0.141	2.226	0.026	Supported
FC → I4.0 adoption	0.427	5.749	0.000	Supported
Moderating effects of PC and PR				
PE → PC → I4.0 adoption	−0.136	1.561	0.119	Rejected
EE → PC → I4.0 adoption	0.028	0.405	0.685	Rejected
SI → PC → I4.0 adoption	−0.068	1.369	0.001	Supported
FC → PC → I4.0 adoption	0.022	0.265	0.791	Rejected
PE → PR → I4.0 adoption	−0.059	1.027	0.305	Rejected
EE → PR → I4.0 adoption	0.066	0.811	0.418	Rejected
SI → PR → I4.0 adoption	0.070	1.650	0.009	Supported
FC → PR → I4.0 adoption	−0.048	0.745	0.457	Rejected

Source: own

to effectively perform and improve overall performance. This phenomenon is commonly referred to as PE. The concept of I4.0 promotes the adoption of information and communication technology (ICT) to drive process innovation, enabling the integration of production processes across the value chain, value network, and product lifecycle. Additionally, it emphasizes product innovation through the utilization of intelligent sensor and actor systems, which facilitate context-sensitive manufacturing processes (Prause, 2019). Therefore, the concept of PE extends beyond the boundaries of the actual performance map, resulting in a noticeable gap within the sector.

Furthermore, it is interesting to note that the impact of EE on I4.0 adoption was found to be insignificant, similar to the effect of PE. This lack of influence can be attributed to various potential factors. According to Kang (2014), there is a consumer preference for technology that is both efficient and user-friendly, and the likelihood of its adoption increases when these two criteria are fulfilled. The adoption

of I4.0 in this particular scenario was a multifaceted concept that was developed by professionals in the fields of software engineering and information technology. Despite its considerable impact on financial activities, consumers were not yet actively embracing this technological advancement. Notably, various scholars have conducted extensive research and have reported noteworthy findings on this subject (Catherine et al., 2017).

In addition, it is worth noting that FC have been identified as statistically significant factors influencing the adoption of I4.0 technology, as supported by recent scholarly publications (Kumar et al., 2022; Wang et al., 2017; Zeqiri et al., 2021). The factors that are perceived to either facilitate or hinder an individual's evaluation of the simplicity or complexity of an activity are referred to as environmental facilitators or obstacles (Teo, 2010). In the realm of technology adoption, there exists a set of FC that can be categorized as either internal or external to organizations. Internally, these conditions encompass factors such as technological expertise, a skilled workforce, and adequate infrastructure. Externally, FC include governmental support in the form of financial resources, training opportunities, and technological guidance. According to Wang et al. (2017), favorable conditions serve as a catalyst for individuals to engage in the exploration of novel technologies. These conditions are perceived as positive signals that promote the utilization of such technologies, facilitating early adoption by consumers and mitigating potential challenges associated with their implementation. Individuals who encounter difficulties in utilizing technology may experience a heightened sense of ease if they receive sufficient assistance. According to Veile et al. (2020), it is crucial to consider financial resources, personnel skills, education, and training assistance as significant factors in the context of I4.0.

In addition, it is interesting to note that the SI factor has a significant and positive impact on the adoption of I4.0 technology. The aforementioned findings align with the research conducted by Mustaqim et al. (2018), and Ronaghi and Forouharfar (2020). Based on scholarly investigations, it has been observed that SI, encompassing the influence exerted by friends, family, coworkers, and peers, significantly contributes to the formation of behavioral intentions in individuals (Ab Jalil et al., 2022; Shen et al., 2019). Individuals hailing from collectivist societies, such as those in Jordan, tend to place greater reliance on subjective evaluations of innovation, which are conveyed by individuals who share similar perspectives and have already embraced the innovation. In contrast, individuals from individualistic cultures prioritize more direct and formal sources of knowledge (Ab Jalil et al., 2022).

The present study investigated the moderating influence of PR and PC on the relationship between UTAUT theory and I4.0 adoption. However, neither PR nor PC demonstrated any significant effects, with the exception of one factor: SI. Several plausible and pragmatic reasons were presented for this outcome. The findings support the assertions made by Veile et al. (2020) that the key resources required for the successful implementation of I4.0 are skilled employees, qualified personnel with a comprehensive understanding of I4.0, and adequate financial resources. The significance of lower PE was found to be critical in effectively implementing technology-based programs. Consequently, the relationship between PE and the adoption of I4.0 was weak and insignificant when considering PC and risk factors within the UTAUT model. Moreover, the adoption of I4.0 technology is not burdened by concerns regarding PC and PR, as it is already a substantial investment and digitalization is already prevalent in the industry. Consequently, there is a significant likelihood of transitioning from a traditional system to a digital-based working environment (Hewavitharana et al., 2021).

According to Schmidthuber et al. (2020), an additional moderator was observed to incur the financial burden of utilizing technology, encompassing costs related to transactions, equipment, application downloads, and access. The notion that the PC of technological innovation can influence its adoption has garnered support from numerous researchers (Shamout et al., 2022; Yadav et al., 2016). The PC does not exhibit a significant moderation effect, with the exception of the SI factor. This implies that the extent to which users perceive the importance of utilizing technology or innovation can vary, influenced by their peers in the industry. As a result, the consideration of cost becomes a significant factor due to the imperative requirement of implementing these technologies, which is influenced by companies operating within the market. Hence, the primary objective

of implementing intelligent machines and autonomous equipment has been to minimize expenses and enhance operational effectiveness. Finally, Hsu et al. (2014) suggested that a significant number of the enterprises involved in the study lack essential technical and proactive skills, specifically in the areas of engineering, information technology, digital capabilities, and the skills necessary for I4.0. This finding suggests that the influence of social factors on the adoption of I4.0 is significantly influenced by the perceived level of risk. This implies that companies will face risks when their peers and senior management contemplate the implementation of I4.0, as it will emerge as a distinguishing factor in the market.

3.3 Managerial and theoretical implications

Our study contributes to the practical and theoretical understanding of the factors that impact the behavior and adoption of new technologies within the context of I4.0. Specifically, we focus on the moderating role of perceived cost and risk in relation to the UTAUT model. This research enhances the existing knowledge base and provides valuable insights. The purpose of this study was to highlight the importance of managerial bodies embracing I4.0 technology. Several implications and insights were observed.

To begin with, the integration of disruptive technologies within the context of I4.0 has the potential to enhance firms' competitiveness by enabling them to adopt cost-effective and efficient manufacturing solutions (Fülöp et al., 2022; Tortorella & Fettermann, 2018). The transition associated with I4.0 occurs within industrial sectors and exerts influence on the broader global context by virtue of the continuous advancement of digital technologies that augment supply chain operations (Fülöp et al., 2022; Jum'a et al., 2022). The implementation of novel business models and services within the context of I4.0 has the potential to enhance overall performance. Manufacturing enterprises ought to give careful consideration to the implementation and utilization of various facets of I4.0. These include digital automation without sensors, digital automation with sensors, remote production monitoring and control using tools like manufacturing operational systems, corrective control systems, and data capture. Additionally, integrated engineering solutions for new product creation and production, additive manufacturing, swift prototyping or three-dimensional printing, modeling and analysis of visual representations (such as computational fluid dynamics) for design and other purposes, utilization of cloud services for products, and integration of digital services into products commonly known as the IoT should be taken into account.

Furthermore, the adoption of this technology can be facilitated by factors such as FC and SI, which can provide support and encouragement to managers. The FC that contribute to the digitalization of the construction industry and subsequently enhance production levels include the proficiency in hardware and software matters, the level of actual knowledge and skills, and the support from top-level management. However, the implementation of I4.0 poses novel challenges for enterprises, especially those operating in developing countries. The present study offers empirical support for the decision-making processes of managers. Specifically, it suggests that managers should give priority to the adoption of product/service-oriented technologies such as cloud services, IoT, or big data analysis, if they have already implemented multiple supply chain management (SCM) practices related to flow. This prioritization is expected to contribute to the attainment of high levels of operational performance (Tortorella & Fettermann, 2018). In the contemporary business landscape, organizations are presented with the opportunity to effectively amalgamate the benefits of real-time integration with the practice of minimizing waste across the entirety of their value chain. In addition, it is imperative to acknowledge the potential challenges associated with the perceived financial implications and uncertainties surrounding the adoption of I4.0. Nevertheless, it is crucial to avoid excessive emphasis on these two factors and instead conduct a thorough evaluation, particularly considering the potential benefits that firms may derive.

In conclusion, it would be prudent for manufacturers to consider the adoption of I4.0 in situations where they face heightened competitive pressures or encounter challenges such as limited performance knowledge, inadequate training capabilities, or a shortage of skilled personnel. Alternatively, failure to adopt I4.0 technologies may result in these enterprises lagging behind their competitors who strategically invest in such advancements to achieve a competitive advantage (Senna et al., 2022).

Therefore, our research provides valuable insights for managers and practitioners regarding the key factors to consider when implementing I4.0 technology in the manufacturing sector in order to enhance operational performance.

In addition to the managerial or practical implications discussed above, this study also highlights several theoretical implications. Scholars exhibit a significant level of interest in I4.0 and the various factors encompassed within the UTAUT that are anticipated to influence its adoption. The existing body of research examining the variables associated with the implementation of I4.0 (Khin & Kee, 2022; Narula et al., 2020) is predominantly characterized by a deficiency in comprehensive investigation and empirical validation. This study presents an empirical investigation of the I4.0 factors within the UTAUT model. The aim is to ascertain and authenticate the factors influencing the implementation of I4.0, as perceived by managers in the manufacturing industry. Consequently, we proposed an expanded UTAUT model that incorporates the factors of perceived risk and cost. The proposed model holds significant value as it addresses a research gap in the literature. While there have been numerous studies examining the acceptability of technology in manufacturing industries, our search yielded limited findings pertaining to the specific model under development. The successful competition of businesses is facilitated by the socio-technical organizational changes that are linked to technology-based environmental practices and behaviors (Kumar et al., 2022).

Conclusions

This study employed the UTAUT framework to examine the adoption of I4.0 technology. Two moderators, namely perceived risk and cost, were incorporated into the analysis. The study examined four factors within the model: perceived expectancy, EE, FC, and SI. These factors were treated as endogenous variables. Additionally, two moderators were incorporated to explore their relationship with the adoption of I4.0. Among the twelve hypotheses examined, a total of four hypotheses demonstrated statistical significance. The adoption of I4.0 was significantly and positively influenced by FC and SI. Furthermore, it was found that the perceived cost and risk variables exerted a significant impact on the relationship between SI and the adoption of I4.0. Hence, numerous scholarly discussions have highlighted the potential impact of these factors on the advancement or trajectory of the arising industrial revolution. This effectively communicates to regulatory bodies and policymakers the imperative to develop strategies and mechanisms that incentivize firms to embrace I4.0.

This study is subject to a small number of limitations. The present study employed a non-probability sampling technique to gather data from manufacturing companies in Jordan. It is important to note that this sampling method may restrict the generalizability of the findings. Moreover, the developed model can be effectively applied to both developing and developed countries. However, the interpretation of the results should be conducted within the specific context of developing countries, and it is crucial to exercise caution when interpreting the results within this context of developing countries. Moreover, this study holds promising prospects for scholars across various paradigms in the future. The study primarily focuses on manufacturing firms in Jordan, but it has the potential to be applied in various contexts by replicating the research in different sectors or countries. Additionally, it is worth noting that the data in this study are cross-sectional in nature. Future research endeavors may consider incorporating longitudinal studies, which would allow for a more comprehensive and extended analysis. In addition, researchers may explore alternative methodologies to further investigate the topic at hand (Kumar Bhardwaj et al., 2021; Tortorella & Fettermann, 2018). Furthermore, conducting cross-country studies could yield more comprehensive and insightful findings, particularly when incorporating developing as well as developed countries within the sample.

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Tab. 1: Constructs and measurement items

Constructs	Measurement items
PE	1. I would find the Industry 4.0 technologies useful in my job. 2. Using the Industry 4.0 technologies enables me to accomplish tasks more quickly. 3. Using the Industry 4.0 technologies increases my productivity. 4. If I use the Industry 4.0 technologies. I will increase my chances of getting a raise.
EE	1. My interaction with the Industry 4.0 technologies would be clear and understandable. 2. It would be easy for me to become skillful at using the Industry 4.0 technologies. 3. I would find the Industry 4.0 technologies easy to use. 4. Learning to operate the Industry 4.0 technologies is easy for me.
SI	1. People who influence my behavior think that I should use the Industry 4.0 technologies. 2. People who are important to me think that I should use the Industry 4.0 technologies. 3. The senior administration has been helpful in the use of the Industry 4.0 technologies.
FC	1. I have the resource necessary to use the Industry 4.0 technologies. 2. I have knowledge necessary to use the Industry 4.0 technologies. 3. The Industry 4.0 technologies are compatible with other systems I use. 4. I think that using Industry 4.0 technologies fits well with the way I like to work. 5. I have knowledge sources (e.g., books, documents, consultants) help me learn about Industry 4.0 technologies.
PC	1. Adopting the Industry 4.0 technologies will increase hardware equipment cost. 2. Adopting the Industry 4.0 technologies will increase operating cost. 3. Adopting the Industry 4.0 technologies will increase maintenance cost.
PR	1. It is probable that Industry 4.0 technologies would not be worth its cost. 2. It is probable that Industry 4.0 technologies would frustrate me because of its poor performance. 3. Comparing with other technologies, using Industry 4.0 technologies has more uncertainties. 4. It is uncertain whether Industry 4.0 technologies would be as effective as I think.
Industry 4.0 adoption	1. Digital automation without sensors. 2. Digital automation with process control sensors. 3. Remote monitoring and control of production through systems such as manufacturing execution system and supervisory control and data acquisition. 4. Digital automation with sensors for product and operating conditions identification, flexible lines. 5. Integrated engineering systems for product development and product manufacturing. 6. Additive manufacturing, rapid prototyping or 3D printing. 7. Simulations/analysis of visual models (finite elements, computational fluid dynamics, etc.) for design and commissioning. 8. Collection, processing and analysis of large quantities of data (big data). 9. Use of cloud services associated with the product. 10. Incorporation of digital services into products (internet of things or product service systems).

Source: own

Navigating the human element: Unveiling insights into workforce dynamics in supply chain automation through smart bibliometric analysis

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Abstract: *This study aims to create a scientific map of supply chain automation research focusing on human resources management, which will be applicable in practice and widen the knowledge in theory. It introduces the scientific articles, subject areas and dominant research topics related to supply chain automation, focusing on human resources management. In this study, 509 publications retrieved from the Scopus database were analyzed by a novel methodological approach – a smart bibliometric literature review using Latent Dirichlet Allocation with Gibbs sampling. The study processes scientific articles with automated tools. It uses a novel machine-learning-based methodological approach to identify latent topics from many scientific articles. This approach creates the possibility of comprehensively capturing the areas of supply chain automation focusing on human resources management and offers a science map of this rapidly developing area. This kind of smart literature review based on a machine learning approach can process a large number of documents. Simultaneously, it can find topics that a standard bibliometric analysis would not show. The authors of the study identified six topics related to supply chain automation, focusing on human resources management, specifically (1) network design, (2) sustainable performance and practices, (3) efficient production, (4) technology-based innovations and changes, (5) management of business and operations, and (6) global company strategies. The study's results offer key insights for decision-makers, illuminating essential themes related to automation integration in the supply chain and the vital role of human resources in this transformation. The limitations of this study are the qualitative level of results provided by the machine learning approach, which does not contain manual analysis of documents and the subjectivity of the expert process to set the appropriate number of topics.*

Keywords: *Automation, smart manufacturing, Industry 4.0, supply chain, qualification, workforce.*

JEL Classification: *M12, J24, L23, O33.*

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Introduction

In the aftermath of the pandemic, the fragilities of established logistics processes were laid bare, exposing vulnerabilities that demand innovative solutions. The disruptions in supply chains posed an unprecedented challenge to the logistics industry, prompting a critical reassessment of its operational paradigms. The scars left by the pandemic, coupled with the geopolitical reshaping induced by the Ukraine war, have underscored the imperative for a supply chain that is not only stable but adaptive in the face of multifaceted disruptions (Schmidt, 2022; Wang et al., 2024).

As we step into what is now termed the post-corona economy, a paradigm shift becomes not just an option but a necessity. This transformation is propelled by the intricate interplay of demographic shifts, technological advancements, and the ever-shifting currents of political dynamics (Börsch, 2021). The demographic landscape, particularly evident in Germany, paints a vivid picture where more than half the population is now over 45, and a substantial 21% of women choose not to have children (Federal Statistical Office of Germany, 2023). Simultaneously, the relentless march of technology into both our professional and personal spheres is rewriting the rules. Smart applications and intuitive voice controls are altering how we work and expediting consumer consumption in previously unimaginable ways (Kreutzer et al., 2017). Against this backdrop, the e-commerce industry, a linchpin for logistics, achieved a staggering turnover of EUR 90.4 billion in 2022 (Hell, 2023).

The profound impact of these factors on the post-corona economy has reshaped traditional business landscapes and cast a discernible shadow over the political arena. The political fallout from events triggered by the Ukraine war resonates deeply in the transport and logistics sector. The enforcement of a ban on the activities of Russian and Belarusian forwarders in the EU, solidified by the EU's fifth sanctions package, exemplifies the intricate web of challenges facing the industry (European Council, 2023).

In the intricate dance of global shifts, the repercussions extend beyond supply shortages and permeate the labour market, introducing a new cadence to the challenges faced by the logistics industry. Because of the shortage of truck drivers triggered by geopolitical events, European countries have embarked on a proactive recruitment drive, heightening the competition for skilled drivers and further intensifying the industry's struggle (Schuhmacher, 2023).

As we weave the threads of demographics, technology, and geopolitics into the narrative, the current state of the labour market emerges as a critical player in this stage of transformation. The landscape has evolved into an applicant market, where companies contend for a shrinking pool of skilled and unskilled workers. This obstacle looms large on the horizon of the industry's future success (Telser, 2023).

To mitigate the impact of labour shortages, industrial companies have resorted to measures such as overtime, shift systems, weekend work, and the inclusion of temporary workers (Dietz, 2020). However, opportunities and possibilities materialize within these challenges, and the logistics sector strategically navigates these uncharted waters (Spath et al., 2013). Despite the prevailing belief that human labour will remain a cornerstone of industrial production, Industry 4.0 introduces a nuanced perspective. According to the Boston Consulting Group, Industry 4.0 is anticipated to catalyze a 6% increase in employment in Germany over the next decade, with demand for mechanical engineers surging by up to 10% (Rüßmann et al., 2015). A projected growth of 390,000 jobs in the manufacturing sector between 2015 and 2025 signals a significant imperative for industrial and logistics companies to meet the rising demand for human labour.

However, this surge in demand is juxtaposed against the backdrop of demographic change, prompting an inevitability: the progressive automation of processes (Fuchs & Zika, 2010). Partial or full automation emerges not merely as a rationalization of jobs but as a necessary evolution, guided by the recognition that the current share of jobs susceptible to automation is limited to less than 5% across operational and dispositive roles (Klaffke, 2016). The emphasis shifts towards expanding and refining activities, forging new collaborations between technologies and human labour, necessitating a fundamental redesign of job roles (Schwartz & Riss, 2021), and identifying and developing necessary skills (Poláková et al., 2023; Šajgalíková & Copuš, 2020). Early insights by Altmann et al. (2017) identified two development directions – re-skilling/upskilling and skill polarization – but the spectrum

of potential pathways and areas for research remains broad and intricate.

As follows from the information introduced above, it is crucial to understand new job requirements that arise under new work environments in the context of automation in logistics. This article aims to create a scientific map of supply chain automation research focusing on human resources management, which will be applicable in practice and widen the knowledge in theory.

1. Theoretical background

Numerous authors have immersed themselves in the expansive realm of supply chain dynamics. Over the past years, there has been a noteworthy surge in publications, each delving into various facets of the supply chain, often intertwining with human resources. The following provides an insightful overview of select articles.

This comprehensive literature review is anchored in both systematic and bibliometric analyses. It seeks not only to elucidate the evolving landscape of supply chain literature but also to offer a nuanced perspective on the interplay between automation and its potential impact on employees' working environment.

The burgeoning body covers various topics, from integrating automation in supply chain processes to its synergies with human resources. The systematic analysis forms the bedrock of discerning patterns and trends, while the bibliometric approach adds a quantitative dimension to our understanding of the expanding field.

Furthermore, a concerted effort is made to categorize each publication based on the specific aspects of automation it explores. This nuanced approach provides readers with a roadmap to navigate the diverse terrain of supply chain literature and underscores the potential ramifications of automation on the professional landscape.

1.1 Bibliometric review overview

Obradović et al. (2021) state that the so-called open innovation is becoming increasingly important in the industry and, thus, also in logistics. The authors analyzed 239 articles from the Web of Science and Scopus databases, and the analysis showed that sustainability research, engagement-based human resource practices, and Industry 4.0 are essential future research directions for IS in the manufacturing industry. The increasingly important factor of sustainability shows that reducing production waste and increasing working conditions may be possible. It has gained importance to study the impact of leadership skills, employee training and development, and reward systems on open cultures in manufacturing companies. This study presents an outlook on the trending topics of knowledge sharing, technology transfer between partners, and the impact of open culture.

Bag et al. (2021) are also increasingly addressing the issue of sustainability in the supply chain, recognizing that Industry 4.0 has led to greater demand for horizontal, vertical and end-to-end digital integration, as well as that previous studies show that the adoption of Industry 4.0 significantly impacts the sustainability aspects of a supply chain network. Which, in turn, has a significant impact on the logistics process. For this purpose, they analyzed publications from the Scopus database. The review shows that there are few research papers in the area of managing the sustainability of supply chain networks through Industry 4.0 technologies. They considered 53 articles in this context, 10 of which dealt with smart manufacturing, smart production systems, smart warehouse management systems, smart logistics, and sustainability. Finally, they identified 13 key components of Industry 4.0 that are important in promoting sustainability in the supply chain. They also showed that the degree of influence of the management level must be considered, and managers must address new employment models and establish plans for continuous improvement of the system. The recommendation is to create a collaborative platform to facilitate high-tech research and development.

A very extensive observation was made by Aamer et al. (2020) as part of their research on data analytics in supply chain management, which focused on supply chain management. One of the disruptive data analytics techniques predicted to impact growth, employment, and inequality in the marketplace is the automation of knowledge work. Even more evident is the notion of machine learning. A total of 1,870 articles were analyzed from the Scopus and Web of Science databases based on machine learning. A reduced number of 79 papers dealing with demand forecasting were comprehensively reviewed and used for analysis in this study.

1.2 Systematic review overview

One outcome of a systematic review is the research of Liboni et al. (2019). Their study considers the potential impact of Industry 4.0 on human resource management (HRM) – with a particular focus on employment, job profile, and skill and competency requirements in the workforce – that may affect supply chain management (SCM). The systematic literature review revealed that the literature in this area is in a transitional process, from early studies by German scholars to the current development of new impacts worldwide. Industry 4.0 is the central theme of the literature analyzed and is achieved through the development of employment, skills, competency and learning frameworks. The results show that most of the work is conceptual, and quantitative studies still need to be completed.

In the same way, Vance et al. (2023) consider the maturity model for smart manufacturing as part of their research. Considering the systematic literature review, nineteen experts were selected to review the maturity model related to digital transformation, Industry 4.0, or smart manufacturing; five models from consulting firms were selected based on the author's knowledge of the industry. The chosen models were analyzed to determine ten categories of dimensions. They were then rated on a scale of 1 to 5 according to the extent to which they applied to the ten categories of dimensions. The five consulting firm models have a first-mover advantage, are more widely used in the industry, and are more applicable, but some are costly and lack published detail and validation. The 19 peer review models are not as widely used, not as well known in the industry, and not as easy to apply due to the lack of a web tool for self-assessment, but they are improving. This study shows an exciting approach, as it also looks from a company's maturity level perspective for further technologization.

Another important study highlights the consideration of agile manufacturing and its supply chains. Gunasekaran et al. (2019) reviewed the data on agile manufacturing in their systematic literature review, focusing on the evolution of agility in manufacturing, the characteristics of agile manufacturing, its drivers, and the identification of competencies that can be leveraged for it. Five competencies were identified specifically: transparent alignment, agile supply chains, smart automation, comprehensive workforce empowerment, and technology integration, and their joint use was further explored to create positive multiplier effects. This study also shows a common intersection concerning manufacturing optimization through agility and the targeted use of employees.

1.3 Research gap

The studies introduced in the literature review above aimed to analyze some aspects of supply chain automation, focusing on human resources management. However, literature reviews based on the systematic or bibliometric approach have some limitations. Systematic literature review types of studies are often in-depth and usually process a limited number of documents. Therefore, results are more narrowly oriented (Moher et al., 2015; Page et al., 2021). On the other hand, bibliometric reviews are focused on a broader scope of the researched area. Therefore, as a result, they bring mainly priority trends (Cobo et al., 2011; Eck & Waltman, 2010). One of the top trends in the bibliometric review field of research is using machine learning to identify latent patterns in textual data (Han, 2020; Mariani & Baggio, 2022).

Our study processes scientific articles with automated tools. It uses a novel machine-learning-based methodological approach to identify latent topics from many scientific articles. The study analyzes 509 papers published in 1999–2022 retrieved from the Scopus database.

This approach creates the possibility to comprehensively capture the areas of supply chain automation focusing on human resources management and offer a science map of this rapidly developing area. Finally, we introduce two related research questions to operationalize the main aim:

RQ1: What is the development of scientific articles and subject areas related to supply chain automation focusing on human resources management?

Research on automation and its impact on human resources is dramatically growing, not excluding the supply chain. Therefore, a bibliometric overview of the development of the number of research papers, top journals, and most cited papers could provide good insight into the development of this up-to-date area.

RQ2: What are the dominant research topics on supply chain automation focusing on human resources management?

The number of documents published years related to the topic of this paper is significantly growing. Therefore, we can use machine learning to identify specific research topics from many published scientific articles.

2. Research methodology

2.1 Data

We carried out the literature review using bibliometric analysis and a machine learning approach. Before conducting the smart literature review, we needed to obtain relevant data from the Scopus database. We decided to use this database because it is one of the world's largest and most relevant scientific databases.

After defining our research area, we defined our search query. The search query was composed of three levels, the intersection of which formed the analyzed research area. The first set was automation, the second was supply chain, and the third was human resources. Due to the greatest possible coverage of articles that meet the stated conditions, the synonyms were also defined. It is important to note that the result of the mentioned search query was the set of documents that met all three conditions simultaneously, i.e., they belonged to all three sets simultaneously. The final search query was defined as follows:
("automation" OR "automatization" OR "smart manufacturing" OR "industry 4.0" OR "smart factor*" OR "industry 5.0") AND ("supply chain") AND ("skills" OR "competenc*" OR "job profile" OR "job description" OR "people development" OR "personnel management" OR "human resources" OR "qualification" OR "workforce" OR "labor" OR "labour" OR "employee" OR "employment" OR "workplace" OR "job").

Subsequently, the search criteria were defined. In the Scopus database, the given search query was searched using titles, abstracts, or keywords defined by authors. We carried out the search process in February 2023. The search query's result was 510 documents.

Since abstracts were the key element of our analysis, one document was removed after obtaining the dataset, as it did not have a defined abstract. The resulting dataset thus had a size of 509 observations. The dataset contained nine variables. The dataset's structure was as follows: authors, title, year, source title, cited by, abstract, author keywords, index keywords, and document type.

As part of the bibliometric analysis, documents in individual subject areas were also analyzed, and each record was subsequently linked to 26 subject areas. The affiliation of a particular record was realized based on the journal's affiliation to individual subject areas.

2.2 Topics extraction

In addition to the standard bibliometric review analysis, we also performed an intelligent review analysis. This analysis was based on machine learning techniques and aimed to examine the particular research area in more detail. As part of this analysis, we identified specific topics relevant to the defined research area. This thoughtful review analysis was implemented using the statistical software R. The advantages of processing in R are high flexibility, replicability of the code, and built-in functions for advanced statistical analyses.

Specific topics were extracted through topic modelling text analysis of abstracts of 509 scientific articles. The corpus of abstracts was pre-processed using standard text analysis methodology to make the topic extraction procedure more efficient and correct. Removal of punctuation, removal of numbers, and removal of standard English stopwords were gradually implemented in the corpus of abstracts. We are also stripped of extra spaces. In the end, a stemming process was carried out, resulting in words in their basic form. In addition, in the process of corpus pre-processing, we identified and removed words with general meaning in the researched domain. We also removed words that were not relevant to our research, as these were words that were a standard part of scientific articles. Finally, we released the words that were part of the search query. The entire procedure of pre-processing the text corpus of abstracts was implemented in R software using the tm and Snowball C libraries. Before the topic modelling itself, we created a document-term matrix. The sparse parameter, which determined the criterion for including a word in the corpus, was set to 0.99.

For topic modelling, we used the Latent Dirichlet Allocation method (Blei et al., 2003), also known as LDA. This method is a form of unsupervised machine learning and works on the principles of probabilistic corpus clustering.

The LDA model is a form of a generative probabilistic model. In LDA, the basic assumption is that documents are a random mixture of latent topics (Blei et al., 2003). In addition, we assume that each topic is a mixture of words defined by a word distribution (Blei et al., 2003). The LDA model is a hidden variable model. The posterior distribution of the hidden random variables is observed in documents with the specified words (Blei & Lafferty, 2007). The LDA model is quantified based on the structure of documents and words. One can assume that the LDA model has generated the collection of documents with defined words (Blei & Lafferty, 2007).

The extraction of topics from the corpus of abstracts was done using the topic models library in the R software. The LDA method requires setting the number of topics. There are several approaches to appropriately choosing the number of topics in LDA modelling. Approaches based on statistics test multiple values of k, while the resulting number of topics is selected based on a defined criterion. At first, we implemented a statistical approach to determine the appropriate number of topics. We tested different numbers of topics in the interval from 10 to 150. The resulting number of topics based on the perplexity criterion was 120, which we evaluated as too high since the number of documents that were the subject of our review analysis was 509. For this reason, we finally replaced it with an expert approach, where we tested k from the selected interval $k = \{6, 7, 8, 9, 10, 11, 12\}$. We chose this interval for a proper interpretation of the results.

We used the Gibbs sampling method to estimate the parameters of the LDA model (Griffiths & Steyvers, 2004; Grun & Hornik, 2011). We set the number of iterations of the algorithm to 100. To eliminate the autocorrelation of the results, we only took every 40th observation for parameter estimation. Due to the possible distortion of the results, we abstracted the first 100 iterations when estimating the parameters. For each chosen k, we performed five independent runs, always saving only the best solution. The final number of topics was selected based on the human judgment approach.

We analyzed the consistency of topics according to the structure of the most frequent words in particular topics. For topic visualization, we used the LDAvis library (Sievert & Shirley, 2014).

3. Results and discussion

3.1 Overview of papers, subject areas and research development

A total of 509 thematic-related papers were analyzed from the Scopus database. The given papers covered the last 20 years in terms of time. The beginnings of research can be dated to the turn of the millennium, but until 2018, the researched topic needed to be scientifically more attractive from the point of view of the number of articles. The breakthrough came only in 2019 when the number of articles doubled and increased dramatically in 2021 and 2022, meaning that research interest is very high. Fig. 1 shows the time development of the number of articles and citations.

We can also see from the figure that not only the number of articles is growing but also the number of citations, which means that the research impact of the given papers is growing. Although the number of citations is strongly linked to specific articles and may fluctuate over time (red line in Fig. 1), the number of citations and, thus, the scientific impact of the given topic is increasing (black line in Fig. 1).

Our dataset also contained information about the sources (e.g., particular journals) in which the given papers were published. The Scopus database assigns most sources to one or more categories. The database distinguishes 28 categories, while one resource can belong to several categories. Fig. 2 shows an overview of the number of articles by individual subject areas. The most numerous subject area is ENGI, in which almost 114 papers were published. The second most numerous subject area is BUSI, while it is interesting that most papers were published in this category during the last period (2020–2023) (precisely 72 papers). Even though ENGI belongs to the most numerous category, looking at the lower part of Fig. 2, we can see that the research impact (measured through the number/share of citations) is the highest in the BUSI subject area. Research in supply chain automation focusing on human resources management resonates most among scientists whose main activity area is research into business and organizational environment aspects. However, it must be said that approximately 40% of all documents in the BUSI subject area are also included in the ENGI subject area.

A deeper insight into the dynamics of research development in individual subject areas

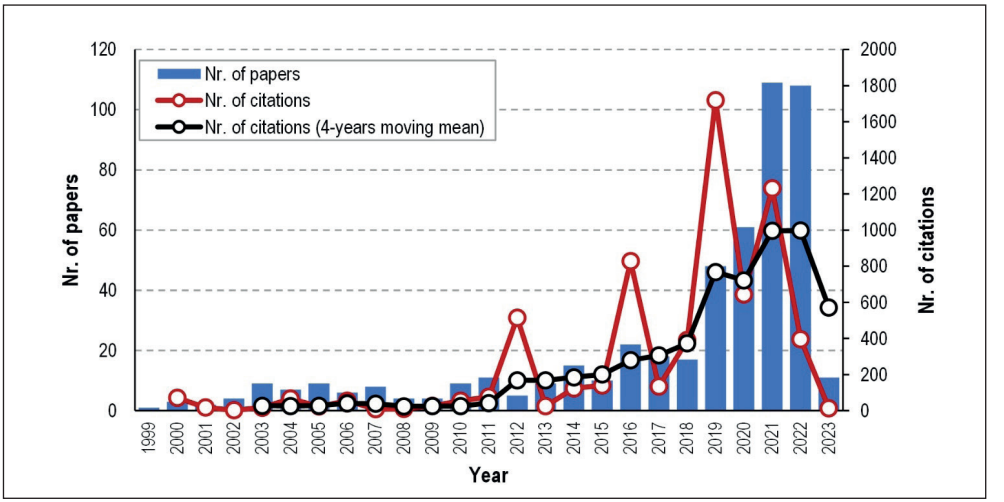

Fig. 1: **Published papers in the last two decades**

Source: own

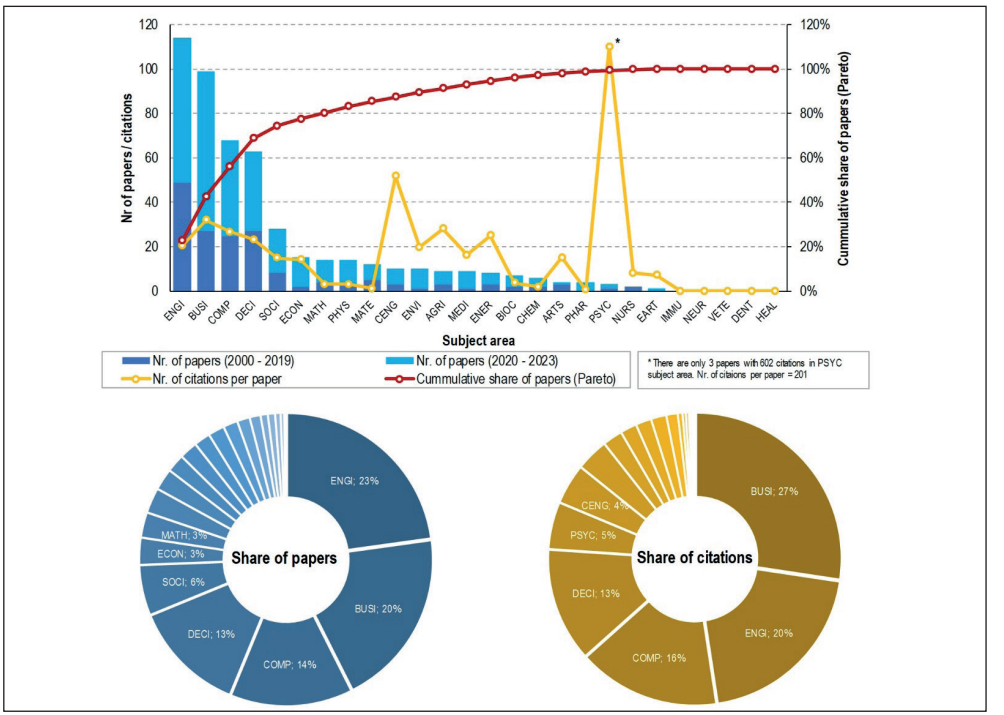

Fig. 2: **Overview of subject areas share (top), papers share percentages (bottom left) and share of citations (bottom right)**

Source: own

can be obtained by analyzing the number of papers in individual subject areas over the last five years. Fig. 3 provides an overview of such developments for the four most numerous subject areas. It can be seen from the picture that the sharp increase in research in supply chain automation focusing on human resources management occurred in 2022 when the number of papers in all four of the most numerous subject areas increased dramatically. Such an increase was primarily related to BUSI and ENGI, while the "lead" over the other subject areas,

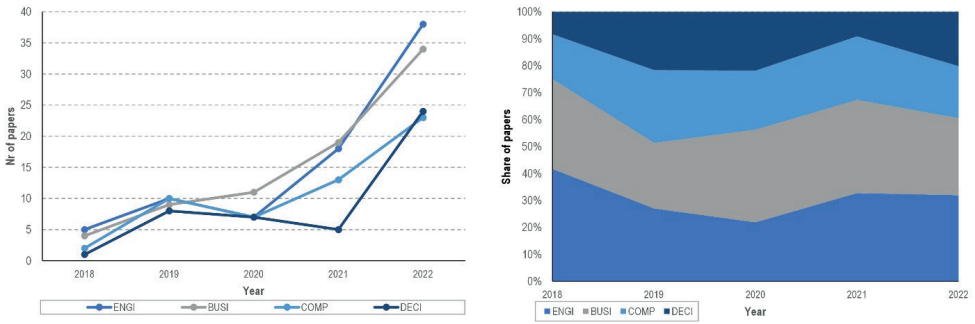

Fig. 3: **Development of papers in top-4 most frequent subject areas – absolute numbers (left) and relative numbers (right)**

Source: own

Tab. 1: **Most influential scientific journals**

Journal	Published papers	Sum of citations (research impact)	Top paper
International Journal of Production Research	10	818	Ivanov et al. (2016)
Technological Forecasting and Social Change	3	602	Horváth and Szabo (2019)
Computers and Chemical Engineering	1	490	Davis et al. (2012)
Journal of Manufacturing Technology Management	4	386	Nascimento et al. (2019)
Computers in Industry	3	182	Galati and Bigliardi (2019)
Benchmarking	2	178	Bag et al. (2021)
2016 IEEE Congress on Evolutionary Computation, CEC 2016	1	171	Shamim et al. (2016)
Resources, Conservation and Recycling	2	155	Kumar et al. (2021)
Annals of Operations Research	1	132	Kalayci et al. (2016)
Journal of Purchasing and Supply Management	2	128	Arlbjørn and Mikkelsen (2014)

Source: own

COMP and DECI, began appearing in 2021. It can be assumed that the years 2021 and 2022 were characterized by the direct effects of the pandemic, which implicitly required the research of possibilities that the automation issue brings.

A specific view of supply chain automation research focusing on human resources management can also be obtained by analyzing the most influential journals. At the time of data collection, 6,593 citations were reported for all analyzed research papers in a total of 359 sources (journals, proceedings, books). Almost half of all citations (3,242) were related to the ten most influential journals. Their overview and the top papers can be found in Tab. 1. The journals' focus points to the research's interdisciplinary nature, as in many cases, the given journal focuses on topics at the interface between BUSI and ENGI. At the same time, it can be seen from the table that up to half of the top papers were published in the last four years (2019+), yet their research impact was very high.

3.2 Topics interconnected with supply chain automation focusing on HRM

We used probabilistic clustering based on the Latent Dirichlet Allocation (LDA) approach to identify and analyze topics. With its help, it was possible to identify groups of similar documents concerning their content. Before the analysis, several experiments took place to determine the optimal number of topics. The expert approach determined the number of latent topics at k = 6. Each of these six topics is characterized by terms with different frequencies (Fig. 4).

Fig. 4 shows the distribution of six topics in coordinates extracted in the form of principal components (PC1 and PC2). The topic with the highest research interest (measured by the number of articles) is Topic 2, which is also the topic with the highest research impact (measured by the number of citations). Based on the composition of the most frequent terms in individual topics and the frequency of these terms, it was possible to assign names to the topics that more broadly characterize

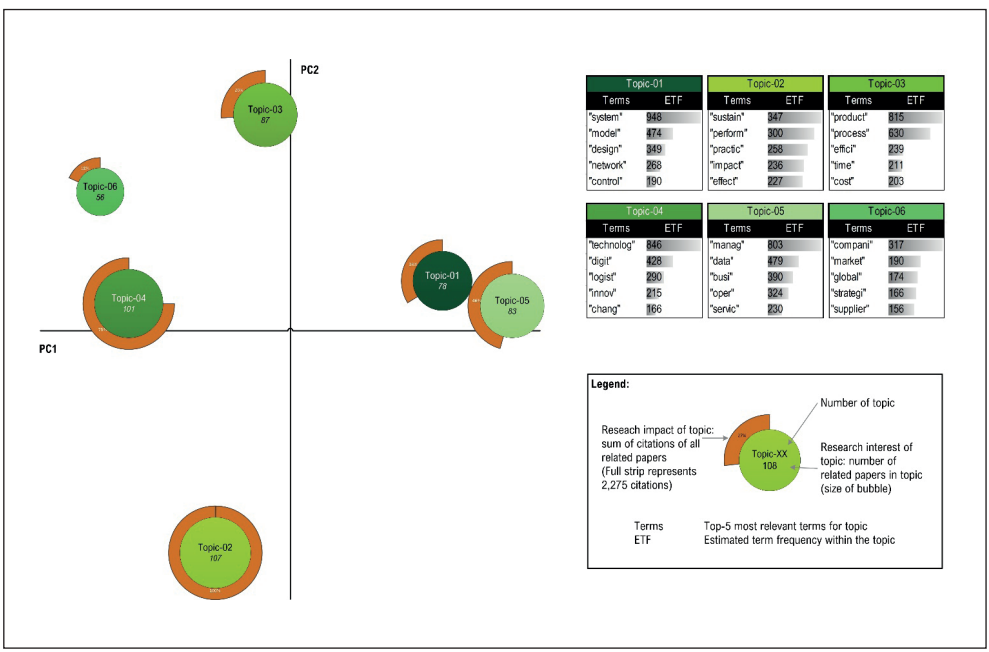

Fig. 4: **Intertopic distance map**

Source: own

the scientific direction of the entire topic of supply chain automation, focusing on human resources management. Below is an overview of the names of these topics with their brief characteristics.

Network design (Topic 1). This topic shows content that is close to concepts such as "system," "model," "design," "network" and "control." This topic has average research interest and average research impact. The listed topics are related to the focus topics on Smart Factories and Industry 4.0 based on collaborative cyber-physical systems (Ivanov et al., 2016) and the applications of optimal control for the planning of production, supply chain and Industry 4.0 systems (Dolgui et al., 2019). As part of this topic, Hamdi et al. (2019) consider, in the context of the rapidly developing industry, the increasing complexity and demands on the daily work of employees and the increasing dynamics on the part of the work environment.

Sustainable performance and practices (Topic 2). This topic was related to sustainability application and performance; the most used terms are "sustain," "perform," "practic," "impact" and "effect." These topics are strongly in focus with the highest research interest and highest research impact. Thus, the Topic 2 represents the most interesting part of the topics. Currently, the following focus topics are of research interest. Liboni et al. (2019) consider the implications in the area of human resources in the context of Industry 4.0 – specifically, on job profiles and skill and competency requirements in the workforce – that may impact supply chain management. Another approach is taken by Ralston and Blackhurst (2020). They consider intelligent systems to increase the resilience of supply chains; in this context, the loss of human capability was also considered, which could be listed as a disadvantage of increasing intelligent systems.

Efficient production (Topic 3). Topic 3 is related to efficiency and process optimization within manufacturing companies with average research interest and lower research impact. The most used terms are "product," "process," "effici," "time" and "cost." In this topic, Kudelska and Niedbał (2020) considered the impact of technological and organizational innovations in the warehouse process on the efficiency of picking processes and employees' workload at picking stations. Complementing this, we found in the research of Waschull et al. (2020) particular details about the rapid advances in several digital technologies and applications. This progress is expected to lead to a whole new level of process automation, redefining the employee's role and thus significantly impacting workplace design.

Technology-based innovations and changes (Topic 4). The following topic strongly connects to the innovation and technology-based approach, which has a high research interest and relatively high research impact. The most used terms in this topic are "technolog," "digital," "logist," "innov" and "chang." In their study on this topic, Horváth and Szabó (2019) show how, in the context of Industry 4.0, managers interpret the concept of Industry 4.0, the driving forces for adopting new technologies, and the main barriers to Industry 4.0. Klumpp (2017) provides a supplement to the consideration of Industry 4.0 with a focus on logistics; the change in the required competencies within logistics is listed in detail, and the importance of further education and training of logistics employees is emphasized, also taking into account demographic change.

Management of business and operations (Topic 5). The next to last Topic 5 has a strong focus on the topics of management and operations, resulting in the following most listed terms "manag," "data," "busi," "oper" and "service." This topic has average research interest and average research impact. Belonging to this topic, Davis et al. (2012), in their research, highlight the theme of smart manufacturing and the pervasive application of networked, information-based technologies throughout the manufacturing and supply chain enterprise, "smart manufacturing" can be applied as a buzzword here. Kaczmarek (2019) deals with using CPS – logistics offers great potential here and is, therefore, particularly affected by the impact of work organization. New management will be necessary to shape the digital transformation of the company and the associated innovative concepts of human resource management. Game-based approaches offer great potential for developing the necessary employee competencies in the context of transforming the working world through Industry 4.0.

Global company strategies (Topic 6). Topic 6 shows a stronger expression in the global corporate strategies, which results in the following terms "company," "market," "global," "strategy" and "supplier." This topic has the lowest research interest and lowest

research impact. In this topic, Dimovski et al. (2019) considered the context of advancing demographics to maintain the declining functional capabilities of the ageing workforce and the productivity of older workers at a higher level while their functional capabilities decline, collaborative robots and smart workplaces are then recommended. Another study by Mason et al. (2022) was done in Australia. It focused on Australian manufacturers using Industry 4.0 technologies to collect, integrate, and analyze data automatically. Employee roles were restructured to enable this, and new skills were developed. Knowledge sharing and collaboration within and across organizations were important for small Australian manufacturers to maintain global competitiveness. This review also highlights the collaboration and evolution between advancing automation and workforce integration.

Fig. 5 contains subject relationships between topics and areas in Circos view (Krzywinski et al., 2009). The topic with the greatest research interest and impact is Topic 2, which includes articles on sustainable performance and practices. Articles on this topic are primarily published in the subject BUSI, although this area does not contain the highest number

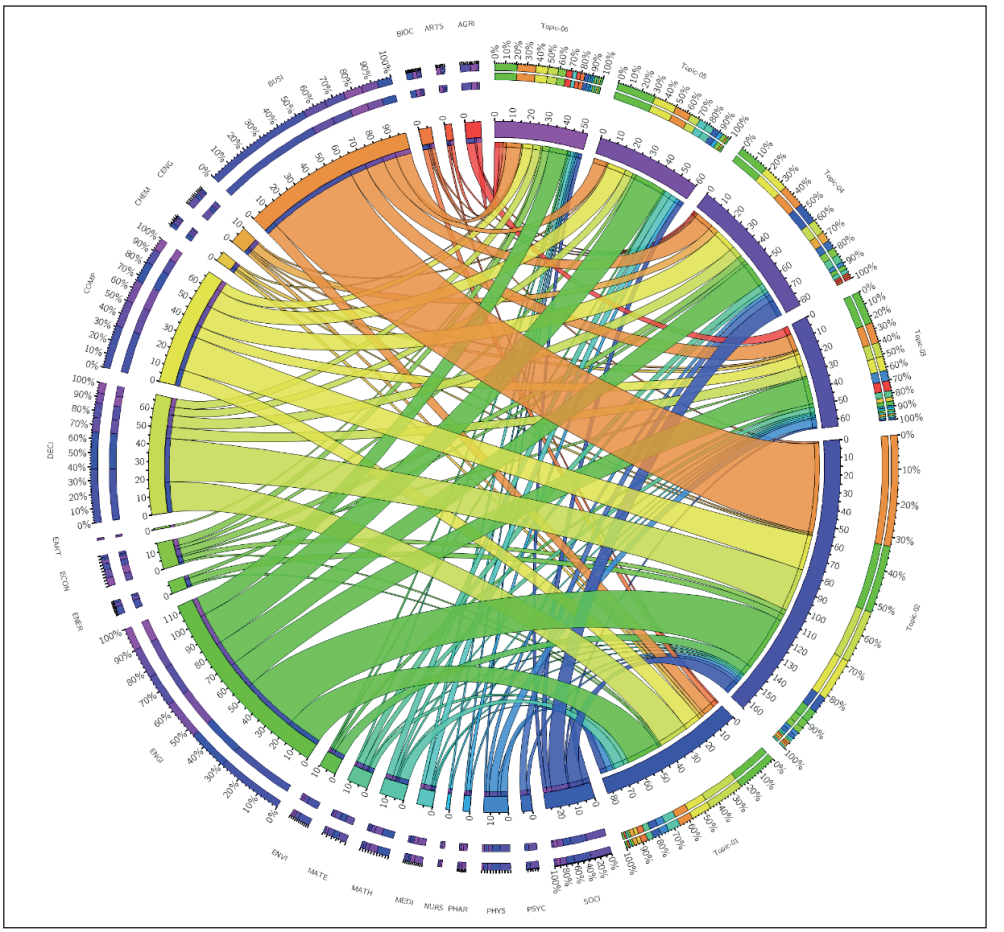

Fig. 5: **The relationships between topics and subject areas**

Source: own

of articles. This means sustainability is essential for scientific research, especially in managing organizations, followed by subjects such as ENGI and DECI. A significant finding is that the ENGI area publications are evenly distributed in all identified topics. This area emphasizes all the aspects of supply chain automation and focuses on human resource management.

Conclusions

Our study focuses on developing a science map of supply chain automation research focusing on human resources management, which checks whether new work environments and, thus, new job requirements arise in the context of automation in logistics. Two research questions were formulated based on the main goal, and the research gap was identified. The most important findings answering the research questions and lowering the research gap are the following:

i) A total of 509 thematic-related papers were analyzed from the Scopus database. The number of papers has risen sharply in recent years, showing an apparent increase in research interest in the area. A strong development was evident in 2019 (the number of articles doubled and increased dramatically in 2021 and 2022);

ii) The number of articles has been growing in recent years (research interest), and the number of citations is growing (research impact). At the time of data collection, 6,593 citations were reported for all analyzed research papers in 359 sources (journals, proceedings, books);

iii) Almost half of all citations (3,242) were related to the ten most influential journals, e.g., International Journal of Production Research, Technological Forecasting and Social Change;

iv) The thematic-related papers can be divided into six topics: network design, sustainable performance and practices, efficient production, technology-based innovations and changes, management of business and operations, and global company strategies;

v) The most influential topic in the meaning of research impact and research interest is Topic 2: sustainable performance and practices. The most significant representation of articles on this topic belonged to the area of BUSI. The research impact is also the highest in the subject area of BUSI.

Exploring supply chain automation research, focusing on human resources management, is gaining prominence in academic circles. This growing significance is underscored by an upsurge in publications (indicating research interest) and citations (reflecting research impact) since 2019. The findings of this study provide valuable insights for decision-makers, shedding light on pivotal and interrelated themes associated with the integration of automation in the supply chain industry and the crucial role of human resources in this transformative process. While individuals remain pivotal in the era of Industry 4.0 for seamless interaction with technology (Xu et al., 2021), Industry 5.0 principles further accentuate the importance of human-centric approaches, sustainability, and resilience (Voitko et al., 2022).

In the analysis of textual data, sustainability emerges as the predominant topic with the highest research interest and impact. This reaffirms the imperative to delve into new dimensions of technology utilization, particularly concerning human resource management in the supply chain industry (Modgil et al., 2023). Notably, most articles on this subject fall within the BUSI domain, highlighting its critical significance. Despite ENGI having the highest article count, BUSI exhibits the highest research impact across all topics. Researchers engaged in supply chain automation studies focusing on human resources management hail from the ENGI and the business and organizational environment (BUSI) realms. This is corroborated by influential journals that bridge the BUSI and ENGI interface, providing a valuable resource for researchers seeking publication opportunities in this domain.

This study identifies six key topics in supply chain automation, focusing on human resources management. As research in this field grows, so do the number of distinct topics, while less significant ones may merge into broader, more crucial ones. The study also highlights the potential of machine learning tools, particularly for processing unstructured data (Madzík et al., 2023), emphasizing their importance in identifying emerging research topics.

Limitations include the qualitative nature of results compared to a standard systematic literature review, the potential inclusion of irrelevant papers, and the possibility of missing relevant ones. The study acknowledges the subjective aspects of the expert approach used in topic modelling and the potential subjectivity in topic naming.

Possible improvements involve expanding the data source and adjusting the research query with related words. The study suggests examining the development of emerging topics and exploring other aspects such as co-authorship, countries, or keyword analysis for future research opportunities. The growing nature of the researched area presents the opportunity to analyze and discover new research topics beyond the six identified in this study.

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Existing and forthcoming obstacles in adopting technological advances in vulnerable supply chains

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Abstract: *The study on supply chain vulnerabilities presented in this research intends to uncover key indicators influencing the adoption of new technological advancements to enhance supply chain operations. This work used the GRA (grey relational analysis) method to conduct semi-structured interviews with the PQR company's automotive lead design engineer, manufacturing process engineer, and optical process engineer in order to enhance the supply chain process and develop a comprehensive structural relationship to rank them to streamline the supply chain vulnerability (SCV) indicators. From the data analysis and results, cost of implementation (CI), skills gap (SG), and cultural shift (CS) are identified as the top three key indicators. However, environmental concerns (EC), regulatory compliance (RC), and supply chain complexity (SCC) have been identified as the bottom three key indicators, respectively. The study's conclusion assists the company's supply chain vulnerability decision-makers (DMs) in identifying critical signs impeding the uptake of new technology. As a market leader, it constantly seeks to enhance the value of its goods through supply chain management (SCM), strong management teams, and expert decision-making that will boost business performance. This study is innovative in that it uses the GRA approach to rank the important indicators of supply chain vulnerability. Managers and practitioners will benefit from this work as the organization will be able to adapt to new developments in their supply chain process and offer superior services.*

Keywords: *Technological advancements, vulnerable supply chains, obstacles in supply chain, GRA-MCDM approach.*

Jel Classification: *L91, M00, M11, O39.*

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Introduction

Modern supply chains (SC) appear to be more fragile than ever before due to changes in the corporate, ecological, and economic contexts for several reasons. Throughout the past few decades, vulnerabilities have grown in both quantity and severity. Droughts, floods, windstorms, earthquakes, hurricanes, and tsunamis are examples of natural catastrophes that occur more frequently and have bigger financial

repercussions (Luo et al., 2023; Wagner & Neshat, 2010). The SC literature has highlighted the importance of managing vulnerabilities inside the operational structures to prevent emergencies from disrupting the SC. This will help business organizations become more resilient and productive and gain a competitive advantage (Xu et al., 2020). Adopting technological innovations has become a promising innovation in this context. It can enhance information and process resilience, disrupt operational processes within the product and service SC, and facilitate risk management within the intricately linked global SC ecosystem (Chowdhury et al., 2023; Wamba & Queiroz, 2020).

A majority would agree that decreased SC efficiencies and disruptions to SC activities are affecting global supply networks (Sharma et al., 2023). SC are more complicated now than they were in the past. The literature (Luo et al., 2023; Wagner & Neshat, 2010) has documented numerous disruptions that highlight the susceptibility of contemporary SC to disruptions, which can have negative consequences for businesses (Wang et al., 2024). SC complexity can be attributed to several factors, including increased R&D and manufacturing the outsourcing process, relationships between suppliers within supplier networks, reliance on supplier capacities, new technologies (such as RFID and the internet), regulatory requirements (such as post-9/11 security regulations governing food safety), shorter product lifecycles as a result of rapidly shifting customer preferences, and expansion into international markets and production (Gangaraju et al., 2023; Sharma et al., 2023). The notion of supply chain vulnerability (SCV) is still understood primarily on a conceptual and normative level, despite these evident causes of increased SCV and its effect on business performance (Fan et al., 2024; Sharma et al., 2023). SC executives still need to improve their techniques for assessing and controlling SCV, even though it has started getting some empirical backing (Luo et al., 2023; Wagner & Neshat, 2010).

Although it is still largely unknown, SCV is a rapidly expanding field of study in management (Brusset et al., 2023). A broader interest in risk management in various other overlapping areas of public policy management and commercial concern is helping SCV as a subject of study (Zhang et al., 2023). Managers and public policymakers would be better able to comprehend the risk exposure of supply networks and pinpoint the areas where mitigation and risk management are required if they could assess and measure the vulnerability of their supplier networks (Guo et al., 2024). In addition, companies could evaluate the degree of SCV both before and after putting risk management measures in place, re-evaluate the vulnerability as the environment shifts, and monitor SCV over time (Hussain et al., 2023). It is difficult to measure SCV. First, SCV is unable to be directly observed or assessed; instead, it is defined by factors known as drivers of vulnerability, such as SC complexity, customer or supplier reliance, and globalization of the sourcing network.

In light of this shortcoming, the primary goals of this study are to create a quantitative method utilizing the multi-criteria decision-making (MCDM) approach to quantify vulnerability by analyzing its primary indicators and their interdependencies and to show how implementing new technologies can reduce the resulting SCV indicators. The goal of this study is to create a framework for determining and assessing the key indicators for SCV mitigation.

This is how the rest of the paper is structured. A review of the theoretical underpinnings of SCV and related indicators opens in Section 1. The graph approach is explained in Section 2. Findings and commentary are presented in Section 3. Section 3 discusses the discussion and results of the empirical investigation, and the ramifications. The last section offers limitations and suggestions for further investigation as the paper comes to a close.

1. Theoretical background

1.1 Supply chain vulnerability (SCV) indicators

SCV is an exposure to serious disturbance and a tendency of risk sources and risk factors to exceed risk mitigating strategies, thus leading to detrimental SC consequences (Akhil et al., 2023; Luo et al., 2023; Sharma et al., 2023). According to Guo et al. (2024), a firm's loss is a result of its SCV to a particular SC disruption and SCV is an outcome of certain SC characteristics. It can be said that vulnerability has mostly to do with anticipatability (Dickens et al., 2023). Since then, the definition of vulnerability in the context of SC has been clearer (Negri et al., 2024; Wagner & Bode, 2009). A disruption in the SC is the catalyst that causes the risk

to arise, but it is not the only factor that determines the ultimate loss. It follows that the SC's vulnerability to the negative effects of this circumstance is likewise highly relevant. The idea of SCV follows from this. The fundamental idea is that SC features influence the likelihood and magnitude of SC disruptions, acting as predictors of SCV.

Within the literature on SC risk and vulnerability, the term "risk" inherently takes on a negative connotation. The earliest and most often referenced author on this topic (Svensson, 2000), contextualized vulnerability and associated ideas, including risk, uncertainty, and reliability, within the broader idea of contingency planning. Vulnerability was defined by Xu et al. (2023) as a condition that is triggered by time and relationship constraints in a company's activities in a SC as well as exposure to serious disturbance, resulting from risks throughout the SC as well as risks extrinsic to the SC. The scientific development of a holistic SC discipline requires that breakthroughs be made in the creation of measurement instruments (Chen & Paulraj, 2004; Ruzo-Sanmartín et al., 2024). Accordingly, it is also necessary to measure and quantify SCV (Adana et al., 2024; Kleindorfer & Saad, 2005). Due to its multidimensional nature and the lack of established measures for assessing the variables that determine vulnerability, SCV measurement is generally seen as challenging (Guo et al., 2024; Sharma et al., 2023). In empirical techniques, Pellegrino (2024) and Luo et al. (2023) examined indicators of SCV; Sharma et al. (2023) explored strategies for minimizing SCV. Studies using an analytical method primarily assessed and quantified susceptibility for monitoring and control. As Tab. 1 illustrates, this research has reduced and identified the main SCV. These signs are easily mitigated by the adoption of technological improvements, which also lessens the SCV and its negative impacts on both the focal business and the SC as an ensemble.

Tab. 1: List of major indicators in supply chain vulnerability – Part 1

Indicators	Definition	References
Cost of implementation (CI)	The initial cost of installation is one of the biggest obstacles to the adoption of new technologies. It can be costly to invest in cutting-edge technology, such as IoT gadgets, AI-powered software, or automation equipment, and not all businesses have the funds to do so.	Javaid et al. (2023), Khan et al. (2023)
Skills gap (SG)	Employees frequently need to pick up new skills to adopt new technology. The workforce may lack the necessary expertise, which could make it more difficult to successfully integrate and use technology.	Jackson et al. (2023), McGuinness et al. (2023)
Resistance to change (RTC)	The adoption of technology may result in resistance from management and staff. The effectiveness of new technology can be diminished and the adoption process slowed down by resistance to change.	Jackson et al. (2023), Javaid et al. (2023)
Regulatory compliance (RC)	A multitude of rules and compliance requirements apply to supply networks. It can be difficult to adapt technology while maintaining compliance with these rules.	Jackson et al. (2023), Kulkov et al. (2023)
Supply chain complexity (SCC)	The complexity of SC is rising due to the involvement of numerous partners and stakeholders in global networks. Such complex networks can be difficult to integrate technology into, and it takes a lot of coordination.	Arji et al. (2023), Jraisat et al. (2023)

Tab. 1: List of major indicators in supply chain vulnerability – Part 2

Indicators	Definition	References
Environmental concerns (EC)	Businesses are under increasing pressure to implement eco-friendly procedures. Technology has the potential to increase SC sustainability, but it may also necessitate considerable adjustments to materials and procedures, which can be expensive and difficult to execute.	Jraisat et al. (2023), Khan et al. (2023)
Supply chain disruptions (SCD)	The COVID-19 outbreak brought attention to how susceptible supply networks are to hiccups. Technology can reduce dangers, but it cannot completely remove them. Disruptions in the SC can have an impact on how technology-driven solutions are implemented.	Arji et al. (2023), Jraisat et al. (2023), Paliwal et al. (2023)
Infrastructure and connectivity (IC)	The deployment of technology may be hampered by infrastructure and connection restrictions in specific areas or industries. The advantages of contemporary SC technologies are impossible to fully realize without dependable internet connectivity and communication networks.	Arji et al. (2023), Ciulli and Kolk (2023)
Cultural shift (CS)	Technology-driven SC transformation frequently necessitates an organizational culture change. Workers must accept new methods of operation and recognize the benefits that technology offers to their jobs.	Bialas et al. (2023), McGuinness et al. (2023)
Supply chain transparency (SCT)	Technology has the potential to increase SC openness, but it can also reveal flaws or unethical behavior. Organizations need to be ready to deal with and resolve these kinds of problems when they come up.	Ciulli and Kolk (2023), Jraisat et al. (2023)
Collaboration and communication (CC)	It is essential that all parties involved in the SC – suppliers, partners, and customers – cooperate and communicate effectively. When adopting new technologies, having open lines of communication facilitates the alignment of objectives and expectations.	Kulkov et al. (2023), McGuinness et al. (2023)

Source: own

1.2 Review of similar works

Due to businesses expanding globally in search of cost reductions, market access, and risk management, the complexity of supply chain management (SC) has expanded. But this has also increased a company's susceptibility to disruptions in supply chains brought on by geopolitical events. Resiliency, vulnerability, and risk are three connected but different concepts that describe systems that face threats, according to Tsang et al. (2024). Studies examining the role of emerging ITs in lowering SCV have been conducted, however many of them focus on specific technologies. One area of emphasis has been the application of big data analytics to demand forecasting and bullwhip effect minimization (Dubey et al., 2019). As demonstrated by outsourcing, internal business practices also have a big impact on SCV (Karwasra et al., 2021). SCV can also be

made worse by an enterprise's lack of understanding and resource limitations (Kurniawan et al., 2017). Scipioni et al. (2002) assessed SCV using conventional analytic techniques, including failure mode, impacts, and critical analysis. The utilization of network methodologies in the examination of trade-related issues can unveil the diverse attributes and positions of various nodes, the influence of developing nations on bilateral trade ties, and the inherent interconnectedness of trade chains (De et al., 2014). To evaluate supply chain vulnerability, Blackhurst et al. (2018) used Petri nets in conjunction with triangular clustering algorithms, and Wang et al. (2023) used sophisticated network analysis techniques to quantify the supply chain risk in China. By conducting a thorough literature analysis and expert interviews, Guo et al. (2024) employed a comprehensive MCDM DEMATEL-ISM strategy to study developing ITs as well as combined solutions reducing SCV issues. Yang et al. (2021) also developed a Bayesian network-based model to evaluate the vulnerability of the energy SC. These previous studies, however, have not yet examined in detail the current and potential barriers to the manufacturing sector's adoption of new technology in vulnerable SC factors. Prior research on the application of the GRA technique for prioritizing SCV indicators has not been explored.

2. Research methodology

2.1 Data collection and sampling

All of the study's data came from PQR Pvt. Ltd., a Taichung, Taiwan-based corporation. A questionnaire was used to collect the data from specialists employed by different branches of car camera manufacturing companies. Managers and team leaders take into account the confidentiality of the factory's data communication. The information and numbers came from the specialists working in the company's manufacturing and operations departments. This business is thought to be the biggest supplier of car cameras globally.

To build concepts and theories based on case studies, academics have been motivated and encouraged to explore a wide range of issues by the seminal study of Eisenhardt (1989). To examine and prioritize them, a multi-criteria decision-making procedure has been used. The study employs observational techniques and concentrates on questionnaire-based quantitative and qualitative procedures. We first created several topics and criteria to gather the opinions of various target responders from the company's top management. Next, we formulated a series of inquiries. Fifteen professionals from various departments, such as operations, production, and R&D, actively participated in the process. These responders are leaders in the field and have a plethora of experience. An overview of the respondents' demographic data is shown in Tab. 2.

The opinions of the 15 respondents are highly regarded by the academic and professional groups since they have an exceptional background working with manufacturing, inventory management, and logistics. Additionally, to meet the goals of our study, we sought to obtain thorough insights from a variety of reliable experts. This allowed us to look at little details that are typically hard to get from large-scale surveys, such as the ones Kumar et al. (2023) used to manage the opportunities and prioritize the main difficulties in SC distribution during COVID-19. To lessen the obstacles to big data use in sustainable SC, Raj et al. (2023) utilize GRA to argue that because these experts have a plethora of knowledge and expertise that substantially enhances the study, the quality of responses rather than the quantity matters. 15 people indeed answered the survey and the small sample size enables more reliable and accurate findings. The sample should be representative and correctly reflect the population of interest. Making a decision could benefit from expert help. The actual characteristics of the research group are probably represented in the outcomes. It is critical to comprehend the constraints and possible outcomes of the study's small sample size.

Initially, for the evaluation of identified SCV indicators, a group of experts for the decision-making process is assembled. During the decision process, if there is hesitancy in deciding on the identified SCV indicators. Then, in that case, go back to the literature for re-evaluating the indicator. Then, after gathering the responses, we identified fifteen DMs from the respondents. Eleven critical indicators are discovered from the semi-structural interview and the current literature. Fig. 1 displays the flowchart of the recommended research effort for the current study for prioritizing the SCV indicators.

2.2 Grey relational analysis (GRA) method

As per Chatterjee and Chakraborty (2014), the grey system theory defines grey as primitive data that have weak, incomplete, and uncertain

Tab. 2: Demographic details of respondents

Profile	Classification	Count
Respondents	Male	6
	Female	9
Age (years)	Under 21	0
	22–32	3
	33–41	4
	42–51	7
	52–61	1
	Over 62	0
Work experience (years)	1–5	1
	6–11	4
	12–21	3
	Above 22	7
Designation of respondents	Camera test instrument engineer	3
	Automotive lead design engineer	2
	Manufacturing process engineer	7
	Optical process engineer	3
Education	Bachelors	5
	Post graduate	6
	PhD	3
	Others	1
Department of respondents	Operations management	2
	Production management	5
	R&D	4
	Production engineering	4
	Others	0

Source: own

information, and the grey relation is the imperfect information relation among these data. The computation of grey relational coefficients (GRC) to address unclear systematic difficulties with only partially available information is defined as a grey relational generation (GRG) by Hamzaçebi and Pekkaya (2011). Rather than depending on expert judgment, the GRA technique is widely implemented, computed, and utilized to choose and rank performance alternatives. Based on this sequence, a reference sequence (RS) (ideal target sequence) is created, and the GRC between each comparability sequence (CS) and the RS is then calculated. These coefficients are then used to calculate the grey relational (GR) grade. An alternative is considered best if the CS translated from it has the highest GR grade between the RS and itself. The last alternative is considered the worst. The following is a list of the steps involved in the GRA technique (Kumar et al., 2023; Lotfi, 1995; Raj et al., 2023).

Step 1: GRG (normalization)
To turn all of the performance numbers for each choice into a comparable sequence, normalizing (also referred to as GRG or data

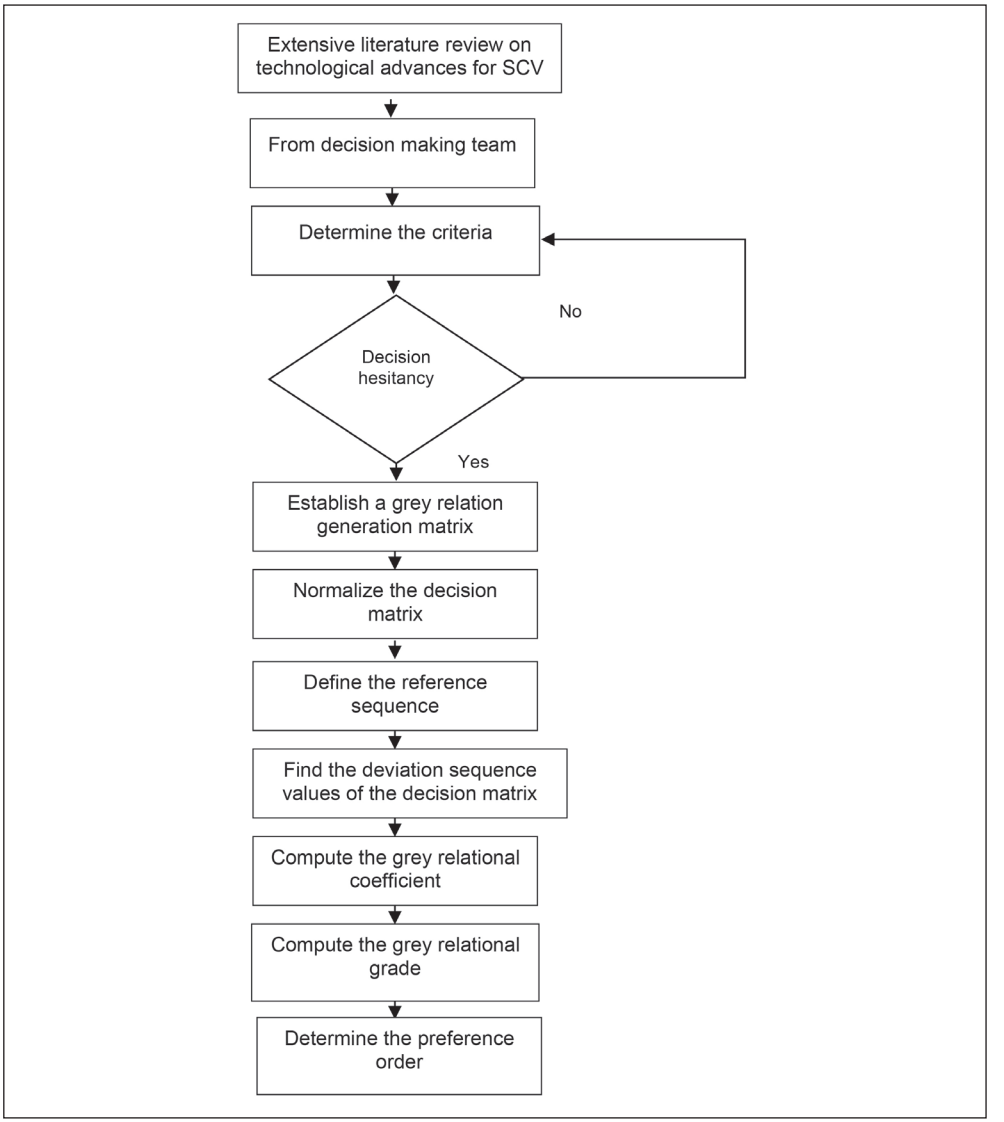

Fig. 1: Flowchart of the proposed research work

Source: own

preprocessing) is required when the units of numerous selection criteria disagree. If there are m options and n criteria in a decision-making problem, the a^{th} alternative can be written as $Q_a = (q_{a1}, q_{a2}, ..., q_{ab}, ..., q_{an})$, where q_{ab} is the performance value of criterion b of alternative a.

Using Equation (1) or Equation (2), the term Q_a may be converted into the relevant CS, $P_a = (p_{a1}, p_{a2}, ..., p_{ab}, \ldots, p_{an})$ (Equation (2)). The decision matrix can be normalized using Equation (1) if the criterion is helpful, i.e., a greater value is desirable. Equation (2) can be used to normalize non-beneficial criteria.

$$p_{a,b} = \frac{[(q_{ab}) - \min(q_{ab}, a = 1, 2, \dots, m)]}{[\max(q_{ab}, a = 1, 2, \dots, m) - \min(q_{ab}, a = 1, 2, \dots, m)]} \quad (1)$$

$$p_{a,b} = \frac{[\max(q_{ab}, a = 1, 2, \dots, m) - (q_{ab})]}{[\max(q_{ab}, a = 1, 2, \dots, m) - \min(q_{ab}, a = 1, 2, \dots, m)]} \quad (2)$$

Step 2: Define the RS

Once the GRG operation is completed, the performance values will range from 0 to 1. The alternative performance is the best for criterion *b* if the value p_{ab}, which is normalized using the GRG process, is equal to or closer to 1 than the value of the other alternative. Consequently, the optimal choice will be made if all of the alternative performance numbers are nearly or equal to 1. The reference alternative is defined as $P_0 = (p_{01}, p_{02}, \dots, p_{0j}, \dots, p_{0n}) = (1, 1, \dots, 1, \dots, \dots, 1)$ and seeks to discover the alternative with the most similar CS to the RS.

Step 3: Calculate the GRC (Ψ)

To establish how close p_{ab} is to p_{0b}, the GRC is utilized. Equation (3) can be employed to obtain the GRC. The greater the value Ψ, the closer p_{ab} and p_{0ai} are to each other.

$$\Psi(p_{0,a}, p_{a,b}) = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_{a,b} + \zeta \Delta_{\max}} \quad (3)$$

(for a = 1, 2, …, m and b = 1 ,2 ,…, n)

where:

$\Psi(p_{0,a}, p_{a,b})$ is the GRC between $p_{a,b}$, $p_{0,a}$,

$\Delta_{a,b} = |p_{0b} - p_{ab}|$

$\Delta_{\min} = \min \{\Delta_{a,b}, a = 1, 2, \dots, m; b = 1, 2, \dots, n\}$

$\Delta_{\max} = \max \{\Delta_{a,b}, a = 1, 2, \dots, m; b = 1, 2, \dots, n\}$

and ζ is the distinguish coefficient ($\zeta \in [0, 1]$), generally taken as 0.5.

The differentiating coefficient's function is to increase the GRC's range.

Step 4: Compute the GR grade

Evaluating GRC $\Psi(x_{0a}, x_{ab})$, and GR grade easily obtained using Equation (4):

$$\Gamma(p_0, p_a) = \sum_{b=1}^{n} w_b \Psi(p_a, p_{ab}) \quad (4)$$

(for a = 1, 2, …, m)

where: $\sum_{b=1}^{n} w_a = 1$

And the weight of the b^{th} criteria (w_b), is assigned by the DMs. The GR grade indicates the degree of correlation, between the RS and the CS. The best option is indicated if the CS of an alternative has the highest GR grade with the RS, indicating that the CS and the RS are the most similar.

3. Data analysis and results

The research report's study questions comprise fifteen decision-makers (DMs) from senior management who provide PQR Pvt. Ltd. with best practices. Every single one of the fifteen DMs (DM1 to DM15) has had good experiences. Using semi-structured interviews with the designated decision-makers and existing literature, a list of eleven key SCV indicators that the manufacturing company has used to efficiently manage the SC process. Furthermore, the primary SC methods have been examined using an MCDM technique GRA to ascertain their priority importance within the sector. Based on the experiences of DMs (DM1 to DM15), scores have been developed for each of these significant SCVs. The decision matrix scores for each of the major SC challenges are shown in Tab. 3.

The main procedure begins with Step 1 of the GRA approach, which transforms the score of each key SC obstacle into a comparability-normalized sequence. The normalized values of the choice matrix are given in Tab. 4. Using Step 2 and this normalized sequence as a basis, RS is calculated and shown in Tab. 5. Step 3 is used to calculate the GRC between each CS and the RS, which is then displayed in Tab. 6. Step 4 is now used to calculate the GR grade between each CS and the RS, which is shown in Tab. 7. Accordingly, based on this computed GR score, the ranking of these important SCV indicators that were identified is displayed in Tab. 7. The higher the grade, the better the option. The final rank of key SC challenges is CI > SG > CS > RTC > SCT > IC > CC > SCD > EC > RC > SCC. Tab. 7 shows cost of implementation (CI), skills gap (SG), and cultural shift (CS), while environmental concerns

Tab. 3: Scores of the decision matrix

Indicators	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10	DM11	DM12	DM13	DM14	DM15
CI	5	4	5	5	5	4	5	5	5	4	5	5	5	4	5
SG	4	3	3	4	4	4	4	5	5	5	4	4	4	5	4
RTC	2	4	3	3	2	3	4	3	3	2	3	4	3	3	2
RC	2	1	2	2	2	3	2	1	1	2	2	2	1	2	1
SCC	3	1	2	2	2	1	2	1	2	2	2	1	2	2	1
EC	1	2	2	1	1	1	3	2	2	2	2	2	1	2	2
SCD	2	3	1	2	1	2	2	1	2	2	2	3	2	2	1
IC	4	3	2	2	3	3	3	2	2	3	2	3	2	2	2
CS	3	4	4	4	3	5	4	4	3	4	3	3	3	2	3
SCT	2	3	4	3	3	3	2	3	3	3	3	2	3	3	3
CC	2	3	2	2	1	1	1	3	2	2	2	2	2	3	2
Min	1	1	1	1	1	1	1	1	1	2	2	1	1	2	1
Max	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5

Note: CI – cost of implementation; SG – skills gap; RTC – resistance to change; RC – regulatory compliance; SCC – supply chain complexity; EC – environmental concerns; SCD – supply chain disruptions; IC – infrastructure and connectivity; CS – cultural shift; SCT – supply chain transparency; CC – collaboration and communication.

Source: own

Tab. 4: Normalized decision matrix

Indicators	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10	DM11	DM12	DM13	DM14	DM15
CI	1.00	0.75	1.00	1.00	1.00	0.75	1.00	1.00	1.00	0.75	1.00	1.00	1.00	0.75	1.00
SG	0.75	0.50	0.50	0.75	0.75	0.75	0.75	1.00	1.00	1.00	0.75	0.75	0.75	1.00	0.75
RTC	0.25	0.75	0.50	0.50	0.25	0.50	0.75	0.50	0.50	0.25	0.50	0.75	0.50	0.50	0.25
RC	0.25	0.00	0.25	0.25	0.25	0.50	0.25	0.00	0.00	0.25	0.25	0.25	0.00	0.25	0.00
SCC	0.50	0.00	0.25	0.25	0.25	0.00	0.25	0.00	0.25	0.25	0.25	0.00	0.25	0.25	0.00
EC	0.00	0.25	0.25	0.00	0.00	0.00	0.50	0.25	0.25	0.25	0.25	0.25	0.00	0.25	0.25
SCD	0.25	0.50	0.00	0.25	0.00	0.25	0.25	0.00	0.25	0.25	0.25	0.50	0.25	0.25	0.00
IC	0.75	0.50	0.25	0.25	0.50	0.50	0.50	0.25	0.25	0.50	0.25	0.50	0.25	0.25	0.25
CS	0.50	0.75	0.75	0.75	0.50	1.00	0.75	0.75	0.50	0.75	0.50	0.50	0.50	0.25	0.50
SCT	0.25	0.50	0.75	0.50	0.50	0.50	0.25	0.50	0.50	0.50	0.50	0.25	0.50	0.50	0.50
CC	0.25	0.50	0.25	0.25	0.00	0.00	0.00	0.50	0.25	0.25	0.25	0.25	0.25	0.50	0.25
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.25	0.00
Max	1.00	0.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Note: CI – cost of implementation; SG – skills gap; RTC – resistance to change; RC – regulatory compliance; SCC – supply chain complexity; EC – environmental concerns; SCD – supply chain disruptions; IC – infrastructure and connectivity; CS – cultural shift; SCT – supply chain transparency; CC – collaboration and communication.

Source: own

Tab. 5: Deviation sequence values

Indicators	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10	DM11	DM12	DM13	DM14	DM15
CI	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.25	0.00
SG	0.25	0.25	0.50	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.25	0.25	0.25	0.00	0.25
RTC	0.75	0.00	0.50	0.50	0.75	0.50	0.25	0.50	0.50	0.75	0.50	0.25	0.50	0.50	0.75
RC	0.75	0.75	0.75	0.75	0.75	0.50	0.75	1.00	1.00	0.75	0.75	0.75	1.00	0.75	1.00
SCC	0.50	0.75	0.75	0.75	0.75	1.00	0.75	1.00	0.75	0.75	0.75	1.00	0.75	0.75	1.00
EC	1.00	0.5	0.75	1.00	1.00	1.00	0.50	0.75	0.75	0.75	0.75	0.75	1.00	0.75	0.75
SCD	0.75	0.25	1.00	0.75	1.00	0.75	0.75	1.00	0.75	0.75	0.75	0.50	0.75	0.75	1.00
IC	0.25	0.25	0.75	0.75	0.50	0.50	0.50	0.75	0.75	0.50	0.75	0.50	0.75	0.75	0.75
CS	0.50	0.00	0.25	0.25	0.50	0.00	0.25	0.25	0.50	0.25	0.50	0.50	0.50	0.75	0.50
SCT	0.75	0.25	0.25	0.50	0.50	0.50	0.75	0.50	0.50	0.50	0.50	0.75	0.50	0.50	0.50
CC	0.75	0.25	0.75	0.75	1.00	1.00	1.00	0.50	0.75	0.75	0.75	0.75	0.75	0.50	0.75

Note: CI – cost of implementation; SG – skills gap; RTC – resistance to change; RC – regulatory compliance; SCC – supply chain complexity; EC – environmental concerns; SCD – supply chain disruptions; IC – infrastructure and connectivity; CS – cultural shift; SCT – supply chain transparency; CC – collaboration and communication.

Source: own

Tab. 6: Grey relation coefficient

Indicators	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10	DM11	DM12	DM13	DM14	DM15
CI	1.00	1.00	1.00	1.00	1.00	0.67	1.00	1.00	1.00	0.60	1.00	1.00	1.00	0.60	1.00
SG	0.67	0.60	0.50	0.67	0.67	0.67	0.67	1.00	1.00	1.00	0.60	0.67	0.67	1.00	0.67
RTC	0.40	1.00	0.50	0.50	0.40	0.50	0.67	0.50	0.50	0.33	0.43	0.67	0.50	0.43	0.40
RC	0.40	0.33	0.40	0.40	0.40	0.50	0.40	0.33	0.33	0.33	0.33	0.40	0.33	0.33	0.33
SCC	0.50	0.33	0.40	0.40	0.40	0.33	0.40	0.33	0.40	0.33	0.33	0.33	0.40	0.33	0.33
EC	0.33	0.43	0.40	0.33	0.33	0.33	0.50	0.40	0.40	0.33	0.33	0.40	0.33	0.33	0.40
SCD	0.40	0.60	0.33	0.40	0.33	0.40	0.40	0.33	0.40	0.33	0.33	0.50	0.40	0.33	0.33
IC	0.67	0.60	0.40	0.40	0.50	0.50	0.50	0.40	0.40	0.43	0.33	0.50	0.40	0.33	0.40
CS	0.50	1.00	0.67	0.67	0.50	1.00	0.67	0.67	0.50	0.60	0.43	0.50	0.50	0.33	0.50
SCT	0.40	0.60	0.67	0.50	0.50	0.50	0.40	0.50	0.50	0.43	0.43	0.40	0.50	0.43	0.50
CC	0.40	0.60	0.40	0.40	0.33	0.33	0.33	0.50	0.40	0.33	0.33	0.40	0.40	0.43	0.40
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max	1.00	0.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.75	0.75	1.00	1.00	0.75	1.00

Note: CI – cost of implementation; SG – skills gap; RTC – resistance to change; RC – regulatory compliance; SCC – supply chain complexity; EC – environmental concerns; SCD – supply chain disruptions; IC – infrastructure and connectivity; CS – cultural shift; SCT – supply chain transparency; CC – collaboration and communication.

Source: own

Tab. 7: Grey relation grades and ranking

Indicators	GRG	Rank
CI	0.9244	1
SG	0.7356	2
RTC	0.5149	4
RC	0.3711	10
SCC	0.3711	11
EC	0.3730	9
SCD	0.3889	8
IC	0.4508	6
CS	0.6019	3
SCT	0.4835	5
CC	0.3997	7

Note: CI – cost of implementation; SG – skills gap; RTC – resistance to change; RC – regulatory compliance; SCC – supply chain complexity; EC – environmental concerns; SCD – supply chain disruptions; IC – infrastructure and connectivity; CS – cultural shift; SCT – supply chain transparency; CC – collaboration and communication.

Source: own

(EC), regulatory compliance (RC), supply chain complexity (SCC) have been identified as top and bottom three key indicators, respectively. The locations of additional indicators are then measured between the two ends. Additionally, it aids in reducing the SCV and preparing to get beyond these obstacles while implementing current SC innovations.

3.1 Discussion and findings

This work identifies the main factors that make SC vulnerable and explains how to control technological advancements to lessen SCV. The cost of implementation (CI), skills gap (SG), and cultural shift (CS) were ranked as the top three primary factors impacting SC vulnerabilities, according to the research findings. Eleven key markers in all that were impacting SCV were found. The indicators included in this study were taken from the body of existing literature based on factors such as industrial infrastructure, geographic location, and current events. Respondents are asked to use five-point Likert scales to rate these factors. The data is then analyzed using the GRA approach, and the findings indicate which factors are most and least important for the primary indicators that have been determined.

This study has found eleven SCV important markers. According to the SCV, the most important factor influencing the acceptance of new technological advancements is the cost of implementation (CI). It is seen to be one of the largest barriers in the SC since businesses find it difficult to accept new technological advancements due to a lack of funding or the increased cost of innovative technologies. In this study, the skills gap (SG) is the second most important indicator. Each of the relevant stakeholders needs more highly qualified, intelligent personnel with the skills to match the new structure of a digitalized SC to satisfy the improved SC performance (Sharma et al., 2023). The majority of the company's employees lack the necessary abilities to successfully implement the most recent developments in technology (Lee et al., 2023). One of the main causes of SCV is also highlighted as delays in the firm's cultural shift (CS). This research shows that many businesses have not fully utilized new and advanced technologies, even after adopting them (Nguyen et al., 2023). Numerous factors suggest that the workforce was unprepared for the abrupt shift and lacked the necessary abilities and expertise to operate contemporary machinery. Improving partners' understanding and transferring knowledge inside a SC are challenging tasks. Ruel et al.'s (2019) research, for instance, demonstrates

that businesses are discouraged from creating tools for knowledge generation, management, and sharing in an uncertain environment. Additionally, there are significant obstacles that prevent the skills gap from becoming clear-cut skills (Hu & Lyu, 2024). Studies reveal that exchanging knowledge and information is crucial to achieving the goal of creating a long-lasting competitive edge. However, the information we gathered shows how unwilling industrial organizations are to share information, knowledge, and even data. Because there has not been a societal shift, SCs are still vulnerable. Therefore, the managerial role is to underscore how crucial it is for the organization to be aware of the opportunities presented by knowledge management (Lee et al., 2023). To create effective knowledge management for handling SC complexity, there are numerous solutions available. Databases, cooperative online platforms, and software designed to handle disturbances are a few of these technologies. The latter allows users to record and share their experiences.

3.2 Theoretical implications

According to the study, CI, SG, and CS have the highest level of significance in SCV and have an impact on the adoption of current innovations. Creating a framework for decision-making through the use of GRA is the primary contribution of this paper to the literature. In this regard, the literature review is used to first identify the key markers in SCV. Eleven important indicators were finalized for evaluation after the GRA approach was applied to determine whether the indicators affecting SC vulnerabilities for new technology adoption were appropriate, based on the opinions of experts. In addition, the experts were requested to assign a five-point Likert scale rating to each signal. The GRA approach was used to provide the indicator prioritization findings based on experts' ratings. Furthermore, our study has made a significant contribution to the related SCV efforts in identifying key indicators influencing technology adoption. Furthermore, in light of the current situation, practitioners and academicians alike should take into account the findings of the study presented above to implement mitigation methods and use contemporary technology to close supply chain gaps. Identifying the root causes of the SCV would aid in fortifying the SC. Lowering the complexity of SC can help control the vulnerability. Improving the openness of information exchange between suppliers of essential parts and SC process owners could accomplish this.

3.3 Managerial implications

There are various ramifications of this study from a managerial standpoint. Our data analysis and findings can give managers useful insights about SCV. The most difficult component, known as CI, is typically linked to businesses' inability to invest in new technologies or raise the necessary capital due to severe issues with handling and raising capital. Business owners and managers need to understand that they may easily reduce all SCV by investing in digital technologies, such as upgrading outdated equipment or adopting new ones. The workforce's skills gap is another concern. Because there are numerous parties involved in the SC, company managers need to be concerned about their workforce's capacity to operate current equipment. Managers ought to have convened a few professional training sessions to equip their staff with potentially enhanced competencies. After carefully analyzing our data, SC practitioners and managers will be better able to pinpoint the key variables influencing SCV when it comes to implementing new technological innovations.

Because today's SCs are vulnerable in many ways, businesses must combine SC risk and decisions. Operational and incentive integration between SC stages is necessary to achieve this integration (Sharma et al., 2022). Managers should thus acknowledge the significance of SCV. The end-to-end SC would experience less strain as a result, enabling it to better handle disruptions and increase SC surplus via risk reduction and flawless fulfillment. Additionally, businesses must invest in cutting-edge decision-making tools that integrate vulnerability analysis with SC plans and SC objectives.

Conclusions

The goal of the study is to pinpoint the SCV indicators and provide a framework for overseeing the adoption of innovations. In light of this unanticipated circumstance, the business must continue to manufacture and distribute its products while also acquiring raw materials from a variety of vendors and storing them in warehouses. After evaluating related publications, the study discovered several significant

markers. Moreover, they have been prioritized using the GRA technique. Eleven indicators in all are found, emphasized, and measured from the prior research and the semi-structural consultation with the top management. The order of importance of these indicators, which should be taken into account when implementing innovations, was determined using the GRA technique and the GR grade computation. To facilitate the operation of the SC system and create opportunities for achieving business objectives, the organization must focus on and address these indicators. The decision and judgment were solely gathered from the organization's top management, which presents a drawback to the current study. Yet another limitation of our approach to finding subjective biases in choices for SCV indicators is the small sample size. We emphasize the significance it is to consider these biases while ranking SCV metrics. Another drawback is that the present investigation was only done from the viewpoint of the manufacturing company that makes car cameras; however, future studies may do comparable research in other industries and poor countries. The following points clarify the recommendations for future research. The structural relationship simulation between these important SCV and contemporary developments has a great deal of potential. Another opportunity is to examine the mathematical validation of the connection model and preference ranking techniques taking into account diverse techniques. This study can be used for multi-sector companies in the future and concentrated on a comparative analysis with different MCDM techniques. In the future scope of this study, more modeling approaches like Bayesian belief networks could be used in the process of manufacturing and distribution to greatly improve production quality with a variety of operations, productivity, and performance. The study's readers or academics/researchers can improve it because there is still much room for improvement even after the investigation is completed.

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Assessing the impact of exchange rates on international trade in the manufacturing sector of CEE countries: A specific focus on SMEs

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Abstract: *This paper aims to analyze the impact of exchange rates on international trade in the manufacturing sector in selected Central and Eastern European (CEE) countries. To accomplish this, a distinctive combination of econometric techniques is employed, enabling an assessment of both macro- and micro-level perspectives concerning the mutual relationship between foreign exchange rates and international trade. At the macroeconomic level, the examination employs the J-curve methodology, utilizing Johansen cointegration and vector error correction models to assess the influence of currency exchange rate dynamics on international trade within the manufacturing industry in Bulgaria, the Czech Republic, Croatia, Hungary, Poland, and Romania. At the micro level, the generalized method of moments is applied to company data from the manufacturing industry in each respective country. The research period encompasses data spanning from 2011 to 2021. The research findings highlight a significant disjunction between macroeconomic and microeconomic perspectives on the impact of exchange rates within the manufacturing industry. While macroeconomic analysis indicates a general trend towards expected outcomes, such as increased exports and improved trade balance following domestic currency depreciation, miecroeconomic regression analysis reveals a more nuanced picture. Contrary to macroeconomic assumptions, the microeconomic perspective, particularly in the case of Romania and Hungary, suggests that exchange rate effects may have opposite impacts on return on assets (ROA) in the manufacturing sector in tested small- and medium-sized companies. This discrepancy underscores the complexity of exchange rate dynamics and emphasizes the need for nuanced, context-specific analyses when assessing the influence of exchange rate fluctuations on international trade and financial performance.*

Keywords: *Company's performance, exchange rate, international trade, J-curve, manufacturing industry.*

JEL Classification: *F23, F31, F41.*

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Introduction

Exchange rates exert a crucial influence on international trade flows acting as a crucial determinant of competitiveness in the global marketplace (Bahmani-Oskooee & Hegerty, 2011; Bussiere et al., 2009). The value

of currencies significantly shapes the pricing dynamics of exports and imports, thus directly impacting the trade landscape, especially within the manufacturing sector. This sector holds substantial importance in the economies of Central and Eastern European (CEE) countries, as it constitutes a significant proportion of their international trade activities (Dobrzanski, 2018; Farkas, 2017).

In this context, our study delves into the relationship between exchange rates and international trade within the manufacturing sector of selected CEE countries, aiming to address two notable research gaps. Firstly, prevailing research often concentrates solely on either macroeconomic implications or microeconomic considerations concerning the effects of exchange rates on international trade. Our paper endeavors to bridge this gap by adopting a comprehensive approach that integrates both macro and micro perspectives. Through simultaneous examination of the broader macroeconomic trends and the specific impacts on SMEs within the manufacturing sector, we endeavor to offer a more nuanced understanding of exchange rate dynamics in CEE countries and their implications for various stakeholders.

Secondly, while small- and medium-sized enterprises (SMEs) play a crucial role in international trade, there exists a lack of research specifically focusing on their experiences within the manufacturing sector of CEE countries. Eurostat's (2023a) data underscores the substantial role played by SMEs in international trade within the CEE region, with SMEs accounting for approximately 60% of total employment and over 50% of value added in the non-financial business economy. Nevertheless, SMEs encounter myriad challenges in navigating the intricacies of international trade, with exchange rate risk emerging as a prominent concern. Research by Gurgul and Lach (2014) and insights from Badshah and Borgersen (2020) shed light on the adverse effects of exchange rate volatility on the competitiveness and export performance of SMEs, thereby emphasizing the imperative of effective risk management strategies. However, hedging might be difficult in SMEs due to the flexibility of decision-making, financial resources, and accessibility of effective tools. Therefore, Badshah and Borgersen (2020) highlight the prominent role of exchange rate risk as a significant barrier to internationalization for SMEs. To thoroughly understand the complex relationship between exchange rates and international trade in Central and Eastern European (CEE) countries, additional research is required. In particular, a comparative analysis that combines both macro-level and micro-level perspectives would offer a more comprehensive insight into this dynamic.

Specifically, our focus extends to Bulgaria, Czechia, Croatia, Hungary, Poland, and Romania – countries characterized by robust economic growth trajectories in recent years. These nations, all members of the European Union (EU), exhibit a pronounced reliance on the manufacturing sector, which not only contributes significantly to their GDP but also serves as a major source of employment. According to data from ILOSTAT (2024), manufacturing employment constitutes a substantial portion of total employment in these countries, with percentages ranging from 16.8% in Croatia to 25.3% in Czechia, underscoring the sector's pivotal role in shaping their economies. Additionally, GDP figures further highlight the significance of the manufacturing sector, with contributions varying from 12% in Croatia to 21% in Czechia, as reported by the World Bank (2023) data.

The significance of our research is further underscored by the growing integration of these CEE countries into the global supply chain, rendering them increasingly susceptible to international economic fluctuations. CEE countries have historically served as formidable manufacturing bases, with exports in the machinery and transport equipment category alone accounting for a noteworthy share of the EU-27 total. In 2022, CEE represented 19% of the EU-27 total machinery and transport equipment international trade – an increase from 14% in 2011 (Eurostat, 2023b). This trend is indicative of the region's evolving economic landscape, wherein manufacturing prowess assumes heightened importance in the context of international trade dynamics. Moreover, the Eurozone accession of Croatia and the pending accession of Bulgaria further accentuate the relevance of our study. As these nations transition towards adopting the euro, their trade dynamics are poised for significant transformation, particularly concerning their interactions with non-Eurozone counterparts. Thus, elucidating the nuances of exchange rate effects on international trade (both from macro and micro perspectives) assumes paramount

importance for policymakers, businesses, and investors operating within the region.

In light of these considerations, our paper aims to analyze the impact of exchange rates on international trade within the manufacturing sector of selected CEE countries. Spanning the period from 2011 to 2021, our study encapsulates significant economic events, including the Eurozone crisis, the Ukrainian conflict, and the COVID-19 pandemic. Employing a unique blend of econometric techniques, we aim to assess the macroeconomic implications using Johansen cointegration and vector error correction models while concurrently scrutinizing the microeconomic dimensions through the generalized method of moments (GMM) applied to SME-specific data within the manufacturing industry. By doing so, we aspire to offer nuanced insights that can inform policymakers, businesses, and SMEs alike, thereby facilitating informed decision-making and fostering enhanced competitiveness in international markets. While SMEs stand to gain specific insights tailored to their needs and challenges, larger companies can also leverage the findings of our study to optimize their international trade strategies, especially in the strategies within the supply chain, including the SMEs.

1. Theoretical background

The literature review serves as the foundation for delineating the assumptions regarding the impact of exchange rates on international trade within the manufacturing sector of selected CEE economies, with a focus on both macro and microeconomic perspectives. As such, it is structured to align closely with the overarching objectives of our research. This review is bifurcated into two primary sections, initially concentrating on the macro effects of exchange rates, followed by a detailed examination of the micro-level implications.

1.1 Macro level perspective of exchange rate-effects

The relationship between the exchange rate and trade balance has been a subject of extensive debate in macroeconomics. The theoretical premise suggests that a weaker domestic currency should boost exports and reduce imports, thus enhancing the trade balance. Conversely, a stronger domestic currency is expected to have the opposite effect. However, empirical evidence has shown that these assumptions may not hold in all cases and are dependent on data and methodological approaches. An influential theory is Magee's (1973) J-curve theory, which distinguishes between short-term and long-term effects. The initial negative effect of home currency depreciation is followed by a positive effect on the trade balance, forming a J-shaped curve. This theory has undergone extensive examination across various countries, utilizing diverse datasets and employing different methodological approaches. Nevertheless, earlier studies predominantly relied on aggregated international trade data and effective exchange rates, which resulted in notable aggregation bias (Bahmani-Oskooee, 1986; Mahdavi & Sohrabian,1993; Rose & Yellen, 1989). Second-generation studies, such as those by Baharumshah (2002), Bahmani-Oskooee and Brooks (1999) and Bahmani-Oskooee and Ratha (2004), used bilateral exchange rates and bilateral trade balances to decrease the bias. Nevertheless, these studies still suffered from aggregation bias caused by grouping products with different price elasticities into one basket. To address this, third-generation studies emerged (Bahmani-Oskooee & Fariditavana, 2019; Bahmani-Oskooee & Hegerty, 2011; Bahmani-Oskooee & Nasir, 2020), which disaggregated trade balance data at the product level. These studies are particularly relevant in understanding the exchange rate's effects from the perspective of companies in specific sectors.

Bahmani-Oskooee and Kutan (2009) investigated the classical J-curve, focusing on data from 12 countries, including CEE countries, during the estimation period of 1990–2005. Empirical evidence supported the J-curve effect in Bulgaria and Croatia but not in other CEE economies. In a more recent study, Nusair (2013) applied a similar methodology, namely autoregressive distributed lag (ARDL) cointegration and an error correction model, to data from 17 emerging and transitioning countries over the period 1991–2012. While the J-curve effect was evident in Armenia, Georgia, and Ukraine, it was absent in the CEE countries. In their study, Kurtovic et al. (2017) analyzed the impact of the exchange rate on Serbia's export and import demand function during the period 2004–2015. The findings revealed the presence of a J-curve effect in the cases of Germany, Austria, and Croatia. Evidence of the J-curve effect is found in Croatia also

in a study by Stučka (2003). The issue is that due to the country's dynamic trade environment and outliers, the results are somewhat sensitive to the inclusion of dummy variables. Hacker and Hatemi-J (2004) examined the J-curve for Czechia, Hungary, and Poland. They observed a deterioration in the trade balance with Germany shortly after depreciation, followed by a rise to a long-term equilibrium value higher than the initial exchange rate. However, there are studies reporting no, or adverse evidence of a J-curve pattern. For instance, Hsing (2009) explored the J-curve for bilateral trade involving Croatia, Czechia, Hungary, Poland, Slovakia, Slovenia, and the USA. No evidence of the J-curve effect was found in any of the analyzed economies. In a study conducted by Fetahi-Vehapi and Jonuzi (2022), it was observed that Poland and Bulgaria experienced an inverse J-curve effect in their trade with North Macedonia, where the trade balance initially improved and then worsened due to exchange rate fluctuations.

Šimáková and Stavárek (2015) employed the Johansen cointegration test to conduct product-level studies in Czechia covering the period from 1993 to 2013. Their research revealed an enduring relationship between the exchange rate and various sub-trade balances encompassing the manufacturing industry. The findings from these studies demonstrated the advantageous impact of Czech koruna's depreciation on a significant majority of the examined product categories. Similarly, Šimáková (2018) brought attention to a crucial dimension of the exchange rate effect by highlighting the dissimilarity in exchange rate elasticity between depreciation and appreciation. The study uncovered that the intensity of exchange rate effects on bilateral trade relationships fluctuated when considering the effects of depreciation and appreciation in distinct product categories. Such variations were attributed to differing reactions from companies and consumers to changes in prices.

1.2 Micro-level perspective of exchange rate-effects

The traditional view on the exchange rates' effect on the relative domestic and foreign prices states that exchange rate change causes shifts in expenditures between domestic and foreign goods (Benita & Lauterbach, 2007; Betts & Kehoe, 2006; Khan et al., 2010). However, some studies show that exchange rate fluctuations have limited short-term effects on relative prices (Cheong, 2004). In practical terms, domestic currency depreciation typically results in higher import prices for companies operating in countries that function as international price takers, while appreciation leads to lower import prices. The depreciation of the domestic currency can potentially increase the cost of imported inputs, raising the marginal costs and consequently leading to higher prices for domestically produced goods (Kandil, 2004). Additionally, import-competing firms might respond to price increases by foreign competitors to improve their profit margins. The extent of such price adjustments depends on various factors, including market structure, the relative presence of domestic and foreign firms, government exchange rate policies, and product substitutability (Fouquin et al., 2001; Sekkat & Mansour, 2000). In the case of CEE countries, the majority of manufacturing companies rely on imported inputs, encompassing equipment, plant and machinery, and various other materials. Persistent changes in exchange rates could create operational and strategic risks for manufacturing companies operating in international markets, leading to discrepancies in cost and revenue models, changing the competitive landscape, and exposing supply chains to risk. Allayannis and Ofek (1997) argue that exchange rate fluctuations have significant impacts on manufacturing firms as they affect their anticipated future cash flows and, consequently, their overall value by altering the home currency value of their foreign revenues and costs. Nevertheless, their empirical analysis disclosed that manufacturing firms could significantly mitigate their exchange rate exposure by extensively adopting foreign currency derivatives and other hedging instruments.

Dekle and Ryoo (2002) found that exchange rates and cash flow shocks are correlated, but the nature of the correlation could be either positive or negative. In the case of negatively correlated exchange rates and cash flow shocks, the firm suffers from low cash flows when its exchange rate depreciates. The firm's production is constrained at precisely the time when export opportunities are greatest, providing the rationale for the firm to hedge against cashflow shocks. They also found that export volumes are strongly affected by changes in exchange rates and that export prices are sticky in the buyer's currency.

The substantial impact of exchange rate fluctuations on export volumes is not primarily due to alterations in the buyer's currency prices. Instead, it is primarily attributed to the loosening of financing constraints, which can result from the advantageous effects of exchange rate shocks on cash flows or from hedging activities. Dominguez and Tesar (2006) conducted an investigation using firm- and industry-level stock returns to examine the existence of exchange rate exposure. Their findings indicated a significant level of exposure to various exchange rates. They postulated that exchange rate exposure may be linked to several firms- and industry-level characteristics, with exposure being more prevalent in small- rather than large- or medium-sized firms and naturally present in those companies engaged in international economic activities, evidenced by multinational status, international asset holding, and foreign sales.

Sekkat and Mansour (2000) conducted a study exploring the sectoral sensitivity to exchange rate fluctuations in Europe. Their findings indicated that the food, paper products, chemicals, metals, machinery, electrical products, and transport equipment sectors respond differently to changes in exchange rates concerning both exports and imports. In general, these sectors demonstrated a high level of sensitivity in both their exports and imports, with the exception of the transport equipment sector. Fouquin et al. (2001) studied the impact of euro/dollar fluctuations on the European manufacturing industries and found that the energy, food, paper products, machinery, and electrical products sectors were the most sensitive to exchange rate fluctuations for imports and energy, machinery, and transport equipment for exports. The determinants of exchange rate sensitivity were identified as concentration on the supply side and dynamics on the demand side. Šimáková (2017) serves the results of the cross-sectional panel regressions concerning firm size in Visegrad countries. The results demonstrate that smaller companies tend to engage in less hedging compared to larger firms, leading to a higher prevalence of currency exposure. Moreover, the hedging approach varies across different industries. The findings from the cross-sectional panel regressions indicate that hedging against currency risk can significantly influence the nature of exchange rate risk exposure. This is fully in line with Šimáková and Rusková (2019), who compared petrochemical and pharmaceutical companies in their study devoted to the Visegrad region. They found out that the significant effect of the exchange rate on the stock price was evident only in one sector, namely in the pharmaceutical industry, exhibiting limited access to hedging instruments.

From the perspective of SMEs, Demian and di Mauro (2018) observed that the exchange rate effects are more pronounced for currency appreciations than for depreciations, particularly among small firms, which often rely on partnerships with foreign entities to enter export markets. Belghitar et al. (2021) highlight that because of the entry barrier, SMEs tend to impose upper limits on exported quantities in the event of currency depreciation, prompting firms to elevate the prices of their exported goods while maintaining constant volumes. Conversely, small firms operating in highly competitive markets face downward pressure on their profit margins and prices during currency appreciation, negatively impacting their competitiveness and forcing them to reduce export volumes. Furthermore, Fornes and Cardoza (2018) found that exchange rates are perceived to be critical for the performance of business expansion. Their research provides deep insights into the barriers faced by SMEs from emerging economies when conducting business abroad, particularly in discerning among various sources of liabilities.

Overall, the literature highlights the important role of exchange rates in shaping international trade in CEE countries on either a macro or micro level. Exchange rate stability is crucial for promoting international trade, and exchange rate fluctuations can have both positive and negative impacts on the volume and competitiveness of international trade in specific industries.

2. Research methodology

The data analysis is divided into two stages. The first stage covers macroeconomic analysis based on the J-curve modelling. The second stage covers microeconomic insights into the relationship between exchange rates and profitability in the companies in the manufacturing sector.

2.1 Macro level model

Macroeconomic empirical analysis aims to investigate whether macroeconomic fundamentals

are cointegrated with trade balance development in selected CEE countries. In this study, the cointegration test reflects methods demonstrated by Johansen and Juselius (1990). To conduct these analyses, a fundamental prerequisite is to ascertain the stationarity of variables at their original levels. The Johansen cointegration technique is utilized to establish a long-term equilibrium between the observed variables and to confirm the existence of cointegrating vectors in non-stationary time series. The primary mathematical expression utilized is that of a vector autoregressive (VAR) model is as follows:

$$\begin{aligned}&\Delta Z_t = C_0 + \sum i = 1\ K\Gamma_i\, \Delta Z_{t-1} + \Pi Z_{t-1} + \\ &+ \eta_t\, \Delta Z_t = C_0 + \sum i = 1 K\Gamma_i\, \Delta Z_{t-1} + \\ &+ \Pi Z_{t-1} + \eta_t\end{aligned} \quad (1)$$

where: Z_t – a vector comprising non-stationary variables; C_0 – the constant term; η – the white noise term; the matrix variables Γ and Π contain the values of the cointegrating vectors.

Johansen and Juselius (1990) defined two ratio test statistics to determine the number of cointegrating vectors. The first ratio statistics is the maximum Eigenvalue statistics used to test the null hypothesis of exactly *r* cointegrating vectors against the alternative hypothesis *r* + 1 vectors. The second statistics, known as the trace test, is employed to test the hypothesis of at most *r* cointegrating vectors.

For empirical analysis of manufacturing trade, the specified model is as follows Equation (2):

$$\begin{aligned}&\ln TB_{p,t} = \alpha + \beta \ln Y_{d,t} + \gamma \ln Y_{f,t} + \\ &+ \lambda \ln ER_{f,t} + \varepsilon_t\end{aligned} \quad (2)$$

The trade balance in time period *t*, denoted as TB_p, is measured as the ratio of exports from the individual CEE country to country *f* over the imports of the CEE country from country *f* in the manufacturing industry. Y_d represents the measure of domestic income (GDP), while Y_f represents the income of the trading partner *f*. GDP is presented in index form to ensure unit-free representation. ER_f signifies the nominal bilateral exchange rate, where an increase indicates a depreciation of the domestic currency. ε_t is the error term. Based on expectations, an increase in foreign income (Y_f) is anticipated to lead to higher exports to the respective country, implying a positive estimate for the parameter γ. Conversely, an increase in domestic income (Y_d) is assumed to boost imports, resulting in a negative estimate for the parameter β. Additionally, the parameter λ is expected to be positive as a depreciation of the domestic currency should improve the trade balance of the respective industry.

If the variables are found to be cointegrated, vector error correction models (VECM) can be estimated. A short-term dynamic component is incorporated into the long-run model to examine the short-run relationship. Following Hsing (2009), the following error correction model is applied:

$$\begin{aligned}&\Delta \ln TB_{p,t} = \alpha + \sum_{k=1}^{n} \omega_k\, \Delta \ln TB_{t-k} + \sum_{k=1}^{n} \beta_k\, \Delta \ln Y_{d,t-k} + \sum_{k=1}^{n} \gamma_k \Delta \ln Y_{f,t-k} + \sum_{k=1}^{n} \Delta \ln ER_{f,t-k} + \\ &+ \vartheta_k EC_{t-1} + \varepsilon_t \\ &\Delta \ln TB_{p,t} = \alpha + \sum_{k=1}^{n} \omega_k\, \Delta \ln TB_{t-k} + \sum_{k=1}^{n} \beta_k\, \Delta \ln Y_{d,t-k} + \sum_{k=1}^{n} \gamma_k \Delta \ln Y_{f,t-k} + \sum_{k=1}^{n} \Delta \ln ER_{f,t-k} + \\ &+ \vartheta_k EC_{t-1} + \varepsilon_t \sum_{k=1}^{n} \omega_k\, \Delta \ln TB_{t-k} + \sum_{k=1}^{n} \beta_k\, \Delta \ln Y_{d,t-k} + \sum_{k=1}^{n} \gamma_k \Delta \ln Y_{f,t-k} + \sum_{k=1}^{n} \Delta \ln ER_{f,t-k} + \\ &+ \vartheta_k EC_{t-1} + \varepsilon_t\end{aligned} \quad (3)$$

where: *EC* – the disequilibrium term; $\vartheta_k EC_{t-1}$ – the error correction mechanism.

2.2 Micro level model

Due to the nature and volume of input data from companies, we employ panel regression methods, commonly used to examine relationships within a two-dimensional space that combines time and cross-sectional data. Panel data is utilized when there is a collection of units that are related or closely associated with a specific characteristic, allowing for repeated observations over time. In this study, we design a panel framework where the profitability of companies is regressed against both company-specific and

macro-specific determinants. As stated by Nandi et al. (2015), this framework helps to account for unobserved heteroscedasticity among variables and captures their interrelationships. The initial condition for conducting tests and regression analyses in modern econometrics is the stationarity of the time series used. Stationarity implies achieving time series with consistent patterns and stable trends. A unit root test is employed to confirm stationarity. Additionally, multicollinearity among variables is crucial to verify. This was addressed simultaneously by utilizing Pearson's correlation coefficient to detect potential multicollinearity. The regression methods used in this study, such as GMM (generalized method of moments), are suitable for capturing the influence of independent variables on the dependent variable in annual data tracking, as described by Hall (2005):

$$L_{it} = \alpha_1 + \beta_1 * \Delta L_{it-1} + \beta_2 * X_{1it} + \\ + \beta_3 * X_{2it} + ... + \beta_n * X_{nit} + \varepsilon_{it} \quad (4)$$

The dependent variable L_{it} in the formula represents the financial performance of the companies; macroeconomic factors are characterized by the unknown variable X, the regression constant, the final parameter of the regression function, and the residual component are elements in the regression analysis. The model employs factors of current liquidity (*LIQ*), debt/equity ratio (*LEV*), bilateral exchange rates (*EXR*), money market interest rate (*IR*), and annual rate of change of *HICP*. To ensure the adequate explanatory power of the obtained results, all explanatory variables will be tested for their statistical significance. Simultaneously, it will be crucial to examine and confirm the overall robustness of the observed model using the Sargan/Hansen J-test (J-statistics). The Sargan/Hansen J-test evaluates the model's capability to produce consistent results even when subjected to minor parameter variations. The final assessment of the model's robustness will be based on statistical significance, with the results of the probability test expected to exceed the selected significance level of 5%.

2.3 Data

The dataset for SME characteristics between the years 2011 and 2021 is based on the Orbis database. Microlevel modelling covers the period between 2011 to 2021 and is based on the yearly level data from six CEE countries. All-time series used for macro-level estimation cover the same period from 2011Q1 to 2021Q4 but are based on quarterly data. Thus, the analysis encompasses data from Bulgaria, Czechia, Croatia, Hungary, Poland, and Romania over an eleven-year period. Data for the SMEs operating in the manufacturing industry in CEE countries include data on sales,

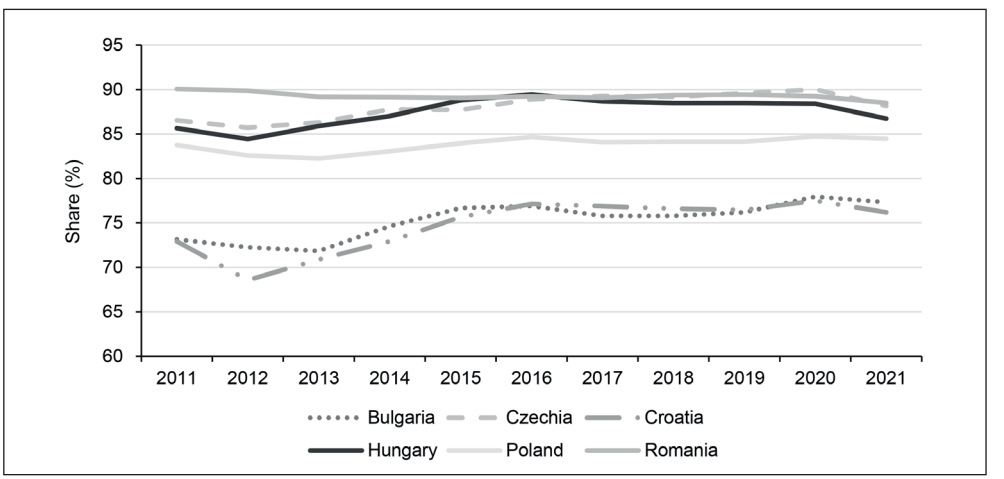

Fig. 1: **Share of manufactured goods in total international trade in goods of respective country**

Source: own

return on assets, level of debt-to-equity ratio, and net income. Subsequently, the Eurostat database was used to obtain macroeconomic data. Specifically, the dataset for each respective country includes total exports and imports of goods, exports, and imports of the manufacturing industry, GDP indicators, inflation, interest rates, and the development of the bilateral exchange rate of local currency against the euro. The manufacturing industry is represented by the Standard International Trade Classification (SITC) 5–8 product categories according to the UNCTAD transfer system. Therefore, this sample covers the sector of chemicals and related products, manufactured goods, machinery and transport equipment, and miscellaneous manufactured articles. The importance of the manufacturing industry in analyzed countries is shown in Fig. 1, which depicts the proportion of the trade with manufactured goods in the total international trade in goods of each country.

Between 2011 and 2021, Romania reached a peak ratio of up to 90%. Czechia, Hungary and Poland also achieved a ratio of more than 80%. On the other hand, Bulgaria and Croatia had the lowest ratios of the countries surveyed. At the same time, it is evident that the trade balance was negatively affected by external economic shocks during the period under review. In 2012, the trade balance was significantly influenced by the global economic crisis. In the subsequent years, 2020 and 2021, the results were negatively affected by the COVID-19 pandemic. Tab. 1 contains basic descriptive statistics in the form of the number of surveyed enterprises that had annual data available and the median values of the microeconomic indicators.

Tab. 1: Descriptive statistics

	Bulgaria	Croatia	Czechia	Hungary	Poland	Romania
Number of companies	12,093	6,087	6,056	14,130	7,099	14,848
ROA	6.28	4.59	4.26	4.93	6.04	5.90
LEV	60.17	46.07	54.41	53.73	55.64	47.04
LIQ	1.57	1.14	1.52	1.05	1.23	1.09
EXR	1.96	7.53	26.33	311.44	4.25	4.57
HICP	0.00	0.70	2.10	2.20	0.90	2.60
IR	1.60	2.77	1.55	3.06	3.20	3.96

Note: *ROA* – return on assets; *LEV* – debt/equity ratio; *LIQ* – current liquidity; *EXR* – bilateral exchange rate; *HICP* – harmonised index of consumer prices; *IR* – money market interest rate.

Source: own (Eviews calculations based on Orbis data)

The total number of analyzed enterprises obtained from all analyzed countries between the years 2011 and 2021 is 55,313. Each ratio is computed based on the individual financial performance of the respective company, resulting in unique ratios for different entities. The calculation is based on the average financial performance of each company, and panel data analysis was employed to derive these outcomes for each state. From the given data, it can be observed that Romania has the highest number of companies, followed by Hungary. Croatia has the lowest number of companies among the listed countries. Return on assets (*ROA*) indicates the profitability of companies in generating income from their assets. Based on the provided data, Hungary has the highest *ROA*, followed by Bulgaria and Romania. Croatia has the lowest *ROA* among the listed countries.

Leverage represents the ratio of debt to equity capital in a company. According to the given data, Bulgaria has the highest leverage, followed by Poland, Czechia, and Hungary. Croatia and Romania have relatively lower leverage values. Subsequently, the measurement of liquidity assesses a company's capability to convert its assets into available cash. Based on the provided data, Bulgaria has the highest liquidity, followed by Czechia and Poland. Hungary and Croatia have lower liquidity values.

In the sample period, *HICP* (harmonized index of consumer prices) indicates the level of inflation in each country. According to the provided data, Romania has the highest inflation rate, followed by Hungary and Czechia. Bulgaria has the lowest inflation rate among the listed countries. Finally, the interest rate represents the cost of borrowing or the return on savings. Based on the given data, Romania has the highest interest rate, followed by Hungary and Poland. Czechia has the lowest interest rate among the listed countries.

3. Research results

The results are divided into two parts, with the first part presenting the outcomes of macroeconomic research, and the second part focusing on microeconomic analysis.

3.1 Results for macro-level perspective

To estimate the long-term relationship between exchange rates and corresponding manufacturing trade balances, we utilize the Johansen cointegration approach applied to Equation (2). This approach can be employed for both stationary data series at their original levels and stationary first-differenced ($I(1)$) variables. This assumption holds for macroeconomic variables in general and is applicable to the data series analyzed in this study. The model is estimated using bilateral data between the selected CEE countries and the Eurozone, as this international trade represents the majority of international trading flows in the CEE region. The results for the long-term relationships obtained from each model are presented in Tabs. 2–3.

Tab. 2: Results of cointegration analysis

	Bulgaria	Croatia	Czechia	Hungary	Poland	Romania
Trace-statistics (none)	128.0304	59.20093	102.2709	92.4594	62.7193	79.5719
Probability	0.0000	0.0163	0.0002	0.0000	0.0070	0.0001
Trace-statistics (at most 1)	47.9210	30.4138	46.6606	53.8205	27.9589	42.5309
Probability	0.0013	0.1496	0.1938	0.0002	0.2431	0.0068
Trace-statistics (at most 2)	26.5543	14.0374	23.0673	27.1258	12.3610	16.1327
Probability	0.0059	0.2868	0.5239	0.0048	0.4170	0.1683
Trace-statistics (at most 3)	9.2936	2.7044	8.3555	6.5536	3.4260	4.2985
Probability	0.0473	0.6372	0.7944	0.1521	0.5043	0.3695
Max-Eigen statistics (none)	80.1094	28.5880	55.6101	38.6389	34.7604	37.0410
Probability	0.0000	0.0472	0.0001	0.0019	0.0071	0.0033
Max-Eigen statistics (at most 1)	21.3667	16.3764	23.5933	26.6947	15.5978	26.3980
Probability	0.0671	0.2724	0.1909	0.0114	0.3278	0.0126
Max-Eigen statistics (at most 2)	17.2606	11.3329	14.7118	20.5722	8.9350	11.8343
Probability	0.0303	0.2281	0.3991	0.0085	0.4408	0.1958
Max-Eigen statistics (at most 3)	9.2936	2.7044	5.2781	6.5536	3.4260	4.2985
Probability	0.0473	0.6372	0.8631	0.1521	0.5043	0.3695

Source: own (based on Eurostat data)

Tab. 3: Number of cointegration vectors

	Bulgaria	Croatia	Czechia	Hungary	Poland	Romania
Number	4	1	1	3	1	2

Source: own (calculations based on Eurostat data)

From the estimated models in Tabs. 2–3, the analysis reveals a general pattern of long-term co-movements between the majority of tested manufacturing trade balances and the variables included in the analysis. The numbers of cointegration equations vary from 1 to 4 and prove the long-term tights between exchange rate and international trade in the manufacturing industry.

The specific models for individual manufacturing trade balances are stated in Equations (5–10). There, we report the statistically significant coefficients of long-term analysis:

$$TB\_Bulgaria = -22.85 - 41.54\ GDP\_Bulgaria + 46.36\ GDP\_EA + 0.52\ Leva \quad (5)$$

$$TB\_Croatia = -4.55 + 0.13\ GDP\_Croatia - 0.15\ GDP\_EA + 2.98\ Kuna \quad (6)$$

$$TB\_Czechia = -43.24 + 3.22\ GDP\_Czechia + 5.88\ GDP\_EA + 0.34\ Koruna \quad (7)$$

$$TB\_Hungary = 131.76 + 37.61\ GDP\_Hungary - 66.33\ GDP\_EA + 0.06\ Forint \quad (8)$$

$$TB\_Poland = -8.88 - 29.26\ GDP\_Poland + 31.32\ GDP\_EA - 0.29\ Zloty \quad (9)$$

$$TB\_Romania = 1.51 - 2.89\ GDP\_Romania + 2.53\ GDP\_EA + 0.22\ Leu \quad (10)$$

We use the GDP of domestic countries as a proxy for home demand for imports from the Eurozone. Therefore, the expected effect of GDP growth on the particular trade balance is negative. The findings indicate that only half of the statistically significant coefficients hold this assumption. Particularly, Bulgaria, Poland, and Romania illustrate that an increase in their GDP is followed by the worsening of the manufacturing trade balance. In contrast, the GDP of the Eurozone represents the proxy for demand for goods from individual CEE countries; hence, we expect the positive coefficients of estimation. In this case, the majority of coefficients followed the theoretical assumption. Exceptions are Croatia and Hungary.

The comparison of employed variables in the model shows that the sizes of the coefficients of exchange rates are lower than the coefficients of GDPs, but they do matter in the development of manufacturing international trade. We employ the bilateral exchange rate quoted in a direct manner, therefore, an increase in it means a depreciation of the domestic currency. Therefore, the expected results are positive coefficients of the exchange rate. Estimations show that almost all tested relationships fulfil this presumption. An inverse relationship is proved only for Poland. This means that the Polish manufacturing trade balance is positively affected by the Polish zloty appreciation. This can be explained by import-intensive export. Albinowski et al. (2017) find that exchange rate movements affect firms' decisions to enter export markets. However, the effect depends on the intensity with which firms use imported intermediates and participate in international production networks. This structure in combination with low hedging used by SMEs in Poland can be followed by an adverse relationship between exchange rate and manufacturing international trade than expected.

Tab. 4 presents the estimates of the short-term effects of exchange rate fluctuations. The results indicate a limited statistical significance of the short-term coefficient for both positive

Tab. 4: Number of cointegration vectors

	Bulgarian leva	Croatian kuna	Czech koruna	Hungarian forint	Polish zloty	Romanian leu
VECM (−1)	−0.21	0.59	0.05	0.05	0.02	1.03
VECM (−2)	1.57	−1.58	−0.40	−0.11	−0.31	−0.06

Source: own (calculations based on Eurostat data)

and negative changes in the tested exchange rates. Nevertheless, there can be an observed pattern concerning the J-curve issue in the case of Bulgarian leva. This means that in the case of the Bulgarian manufacturing trade balance, after the depreciation of Bulgarian leva, one can observe the initial worsening of this trade balance followed by increasing in the levels higher than the initial ones, resembling the letter J.

Policymakers need to factor in the differentiated effects of GDP growth and exchange rate movements on manufacturing trade balances when shaping economic policies. Similarly, businesses in the manufacturing sector, notably in Bulgaria, Poland, and Romania, should remain cautious about the potential adverse impacts of domestic GDP growth on their trade balances. Furthermore, Polish firms should evaluate their vulnerability to exchange rate fluctuations, particularly given the import-intensive nature of their exports and the limited hedging practices among SMEs. Lastly, stakeholders involved in trade finance and risk management should incorporate the observed pattern of the J-curve effect in the Bulgarian manufacturing trade balance into their strategies for mitigating exchange rate risks.

3.2 Results for micro-level perspective

In order to investigate the influence of basic economic aspects on the profitability of firms, the data used in the first stage had to be adjusted into a panel form. Subsequently, the data used was log-logarithmized and a stationarity test was performed on these data. The results confirmed that the data were stationary and were subsequently used for regression analysis using the GMM method. Simultaneously, the results of correlation coefficients indicate the absence of multicollinearity among the observed indicators, as none of the correlation coefficients exceed 0.8. Tab. 5 exhibits the results of the regression coefficients. At the same time, the J-statistics values are also shown, indicating the robustness of the models used.

The provided regression analysis results show the coefficients and statistical significance of the variables in the model for each country. The coefficient *ROA* (−1) represents the effect of the lagged value of *ROA* on the current *ROA*.

Tab. 5: Results of regression analysis

	Bulgaria	Croatia	Czechia	Hungary	Poland	Romania
***ROA* (–1)**	0.23*	0.22*	0.07*	0.29*	0.23*	0.21*
LEV	0.22*	0.23*	0.24*	− 0.01	0.24*	0.26*
LIQ	−0.18*	−0.10*	−0.16*	0.09*	−0.06*	−0.08*
EXR	−1,948.16	0.04	0.30	−0.02*	−1.43	−10.44*
HICP	0.06*	0.39*	0.44*	0.28*	0.06	0.58*
IR	0.27	0.89*	−0.09	0.08	0.29*	−1.06*
J-statistics	15.06	31.35	27.62	24.72	12.15	15.17

Note: * statistical significance at the 0.05 level.

Source: own (based on Orbis data)

The positive and statistically significant coefficients indicate that the past *ROA* has a positive influence on the current *ROA* for all countries. The following coefficient represents the effect of the leverage on *ROA*. The statistically significant coefficients suggest that higher leverage is associated with higher *ROA* for Bulgaria, Croatia, Czechia, Poland, and Romania. However, in Hungary, the impact of the leverage variable on *ROA* is not statistically significant. For the *LIQ*, all statistically significant coefficients indicate that higher liquidity is associated with lower *ROA* for all countries. This suggests that more liquid assets may lead to lower profitability. This discrepancy highlights the nuanced nature of the relationship between leverage and profitability, indicating that country-specific factors and market conditions play a significant role in shaping these dynamics.

Macroeconomic control variables were also examined. Research on these variables is particularly important for the robustness of the results in the model. Statistically significant coefficients of inflation (*HICP*) indicate that higher inflation is associated with higher *ROA* for Bulgaria, Croatia, Czechia, Hungary, and Romania. However, in Poland, the impact of inflation on *ROA* is not statistically significant. The last coefficient represents the effect of the interest rate on *ROA*. In this case, Croatia, Poland, and Romania have statistically significant coefficients, suggesting that the interest rate has a significant impact on *ROA* in these countries. However, for Bulgaria, Czechia, and Hungary, the interest rate does not show a statistically significant relationship with *ROA*. According to the results of the Sargen Hansen test (J-statistics) for robustness of models, it can be confirmed that all models yield statistically significant results.

For SMEs, understanding the nuanced relationship between financial metrics and profitability is crucial. The findings suggest that past performance strongly influences current profitability, highlighting the importance of maintaining consistent financial health. Moreover, the impact of leverage and liquidity on profitability underscores the need for prudent financial management strategies tailored to each country's economic context. SMEs should pay particular attention to the potential adverse effects of excessive liquidity on profitability, especially in countries where this relationship is statistically significant.

In the case of exchange rates, only Hungary and Romania have statistically significant coefficients, suggesting that changes in the exchange rate have a significant impact on *ROA* in the manufacturing of international trade between Romania and Hungary. These two countries have the highest number of companies represented in the data sample. However, the coefficients show opposite relationships to those assessed in the macroeconomic model. The other countries do not show statistically significant relationships between exchange rates and *ROA*. The Bulgarian leva was pegged to the euro in the sample period and has been in the ERM II mechanism, similarly to Croatia. This could affect non-statistically significant results in the microeconomic analysis. Therefore, this study proposes that the effects of exchange rates differ between the macroeconomic and microeconomic perspectives within the manufacturing industry. The magnitude of exchange rate effects on the bilateral trade relationships under investigation shows noticeable disparities when examining the impacts of exchange rate fluctuations on SME data. Moreover, the significant impact of exchange rates on profitability highlights the need for policies that mitigate the adverse effects of exchange rate fluctuations, especially for countries heavily reliant on manufacturing exports.

Overall, the research findings highlight a significant disjunction between macroeconomic and microeconomic perspectives on the impact of exchange rates within the manufacturing industry. While macroeconomic analysis indicates a general trend towards expected outcomes, such as increased exports and improved trade balance following domestic currency depreciation, microeconomic regression analysis reveals a more nuanced picture. Contrary to macroeconomic assumptions, the microeconomic perspective, particularly in the case of Romania and Hungary, suggests that exchange rate effects may have opposite impacts on return on assets (*ROA*) in the manufacturing sector in tested small and medium-sized companies. This discrepancy underscores the complexity of exchange rate dynamics and emphasizes the need for nuanced, context-specific analyses when assessing the influence of exchange rate fluctuations on international trade and financial performance.

Conclusions

This paper analyzed the effects of exchange rates on international trade in the manufacturing

sector in selected CEE countries. The manufacturing sector is an essential part of their economies, and these countries are becoming increasingly integrated into the global supply chain, making them more exposed to international economic fluctuations. Understanding the effects of exchange rates on their manufacturing international trade is crucial for policymakers, businesses, and investors operating in the region. The macroeconomic results showed that only half of the statistically significant coefficients held the assumption that an increase in domestic GDP leads to increased imports and decreased exports resulting in the worsening of the manufacturing trade balance. Although the coefficients of exchange rates were smaller compared to the coefficients of GDPs, they still hold significance in the context of the growth and development of international trade in the manufacturing sector. The expected results were positive coefficients of the exchange rate, and almost all tested relationships fulfilled this presumption, except for Poland. The short-term effects of exchange rate changes were limited, but there was a pattern concerning the J-curve issue in the case of the effects of Bulgarian leva on the manufacturing trade balance between Bulgaria and the Eurozone. In the long run, the combined import and export price elasticities exceed one, indicating a greater responsiveness of trade volumes to changes in prices compared to the short run. The short-term negative impact of Bulgarian leva on manufacturing international trade is followed by the long-term increase in trade balance eventually.

Based on the microeconomic regression analysis results, we can draw conclusions regarding the factors influencing return on assets (*ROA*) across the examined countries. These findings shed light on the intricate relationships between key variables and the financial performance of companies in each respective economy. Firstly, leverage emerges as a factor with varying effects across the countries under scrutiny. While Bulgaria, Croatia, Czechia, Poland, and Romania exhibit a positive relationship between leverage and *ROA*, Hungary displays no statistically significant impact. Furthermore, liquidity levels demonstrate consistent negative associations with *ROA* across all examined nations. This implies that increased liquidity, characterized by a higher ability to convert assets into cash, may hinder overall profitability. The impact of exchange rates on *ROA* is less uniform, with only Hungary displaying a statistically significant relationship. Moreover, inflation exerts an impact on *ROA* in several countries. Bulgaria, Croatia, Czechia, Hungary, and Romania all experience a positive and statistically significant relationship between inflation and *ROA*. This implies that higher inflation rates coincide with enhanced profitability in these nations, potentially signaling a favorable business environment. Finally, the findings reveal that interest rates play a significant role in determining the profitability of companies in specific countries. Croatia, Poland, and Romania display statistically significant relationships between interest rates and *ROA*. The findings underscore the multifaceted nature of profitability determinants, highlighting the significance of factors such as past performance, leverage, liquidity, and inflation.

The exchange rates were found to be statistically significant only in the case of Romania and Hungary. However, the coefficients show opposite relationships to those assessed in the macroeconomic model. Therefore, this study suggests that the impact of exchange rate effects differs between the macroeconomic and microeconomic perspectives within the manufacturing industry. The intensity of exchange rate effects on the examined bilateral trade relationships is notably diverse when considering the effects of exchange rate changes in SME data. The findings of this research demonstrate that the role and influence of the exchange rate on analyzed CEE international trade cannot be generalized. It cannot be assumed that the depreciation of the local currency will automatically enhance exports, reduce imports, and improve the manufacturing trade balance or that the opposite will occur following an appreciation.

The firm's production faces constraints precisely at the time when export and import opportunities are most abundant, prompting the firm to hedge against cash flow shocks. Empirical results indicate that changes in exchange rates affect the performance of international trade flows and that export prices tend to remain fixed in the buyer's currency. The response of international trade volumes to fluctuations in exchange rates stems not only from changes in the buyer's currency prices but also from the relaxation of financing constraints, either through the direct positive impact of exchange rate shocks on cash flows or through hedging activities.

The findings of this study carry important implications for policymakers, investors, or businesses operating in the CEE region. Policymakers can utilize these insights when formulating strategies to support the manufacturing sector and enhance international trade competitiveness. Understanding the nuanced effects of exchange rates on international trade and financial performance is vital, especially for SMEs, given their increasing integration into the global supply chain and exposure to international economic fluctuations. The findings suggest that SMEs need to adopt proactive strategies to manage exchange rate risk effectively and capitalize on export opportunities. Policymakers can use these insights to formulate targeted policies that support SMEs in navigating exchange rate dynamics and enhancing their competitiveness in international markets. Moreover, investors should consider the implications of exchange rate movements on SMEs' financial performance when making investment decisions in the CEE region, while SMEs themselves can leverage these findings to inform strategic decision-making processes, particularly regarding exchange rate risk management and international market expansion.

The study is subject to certain limitations. Firstly, it exclusively focuses on the manufacturing sector within selected Central and Eastern European countries, potentially restricting the generalizability of findings to other sectors or regions. Secondly, reliance on secondary data sources may introduce limitations, including issues related to data availability and accuracy. Lastly, the study predominantly examines the effects of exchange rates on international trade and financial performance, overlooking other potentially influential factors such as political instability or technological advancements. For further research, there is a need to explore the impact of additional variables, such as political stability or technological innovation, on international trade and financial performance within the manufacturing sector. Also, further investigation into the long-term effects of exchange rate fluctuations on trade dynamics and financial performance could provide deeper insights into underlying mechanisms.

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Socio-demographic factors' influence on the energy-saving behaviour of residential consumers: Evidence from Romania

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Abstract: *In the context of various attempts to regulate energy consumption and educate consumers in the spirit of sustainable behavior, this paper aims to identify the role of the main socio-demographic factors on the decision to adopt measures to reduce consumption and save energy. Many studies have approached similar topics, but correlating their conclusions, it can be deduced that psycho-socio-demographic factors interact differently from one country to another, depending on the economic and political context of the moment. From the fact that in the former communist countries, the severe political regime subjected the population to very restrictive living conditions, based on deprivations that led to the formation of a traditional saving behavior and, on the other hand, considering the new Sustainable Development Goals (SDGs) that shape the young generation in the spirit of sustainable society, the authors aimed to study the correlation between socio-demographic factors (age, gender, education, professional status, income) and consumption and energy saving behavior at residential level, in an ex-communist state, Romania. For this purpose, quantitative research was carried out based on the answers of 865 subjects to the questionnaire distributed at the Academy of Economic Studies in Bucharest and in the immediate environment to the members of the university community, using convenience sampling. Using descriptive statistical indicators and linear regression techniques, the intensity of correlation between selected variables was determined and the degree of differentiation of the purchasing and use behavior of green-label household appliances was analysed, as well as the population's availability to adopt some energy-saving methods. Although the sample is not representative, the conclusions are that measures to reduce energy consumption must be voluntary and stratified, depending on the nature of social and demographic factors.*

Keywords: *Sustainability, energy consumption reduction, residential consumer, voluntary measures, influences on saving behavior.*

JEL Classification: *F00, F64, M00, M20, O13.*

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Introduction

More than ever, we are now living an unprecedented experience: on the one hand, in recent decades, with the industrial revolution, the quality of life has centered on consumerist policies (Copeland & Boulliane, 2022; Eriksson & Vogt, 2012; Hou & Poliquin, 2024; Lee & Fong, 2021), which are meant to exponentially increase investors' profits, even at the risk of overproductions whose supply far exceeds the capacity of consumption; on the other hand, the devastating effects of uncontrolled production and consumption (Roy et al., 2022), which are endangering the future of the planet, so that only through huge global efforts, centered on sustainability criteria, the situation can be remedied before it is too late.

With the signing by the United Nations in 2015 of the global framework for an inclusive, just and sustainable society by 2030, 17 Sustainable Development Goals (SDGs) have been promoted as a universal call for action to end poverty, protect the planet and ensure global peace and prosperity (UNDP, 2023). The most recent research of the authors of the present work has focused on SDG7 "Ensuring access to affordable, reliable, sustainable and modern energy," through the perspective of reconsidering the efforts to neutralise the climate and to update the strategic measures imposed by the current geopolitical, economic and social context.

The European strategic projections of recent years aim to adopt the most coherent measures to facilitate the member states of the European Union (EU) transition to an environmentally friendly energy system that accelerates economic growth and climate neutrality by 2050. To achieve the proposed goal and mainly to prevent an energy collapse associated with the degradation of the Russian-European diplomatic relations amid the war in the region, the European Union institutions have also drawn up specific directives aimed at promoting voluntary measures aimed at saving energy at residential level and the transition to green energy in a shorter time than initially anticipated in the 2015 SDG.

In the context of the aforementioned Sustainable Development Goals (SDGs), starting from the most recent European norms, legislation and recommendations (European Commission, 2023) and selecting the best practices adopted at the international level in the field of reducing energy consumption, the authors made a diagnosis regarding the specific market of consumers in Romania. Integrating itself as a continuation of the research mentioned above, the purpose of the present work is the analysis of the behavior of the Romanian household consumer towards the voluntary measures to reduce energy consumption at the residential level in terms of correlations between age, level of education, and the average level of income and energy price.

By capitalising on the studied specialised literature and the practical conclusions resulting from the experience of other countries of the world (Belgium, Canada, France, Germany, Italy, Norway, Poland, Sweden, and the USA) in the field of energy consumption at the residential level and appreciated by us as a representative, it was analysed the behavior of consumers, based on the responses of the sample of respondents and the availability of household consumers to outline a sustainable consumer profile.

This paper, regarding a possible change in energy consumer behaviour, is elaborated in the context of recommendations of the recent European document RePowerEU, adopted on February 14, 2023 (European Commission, 2023), which highlights that the population of the energy consumption sector represents about one-third of the total consumption, can be a source of saving and preventing a deep energy crisis, by adopting voluntary measures to reduce uncontrolled energy consumption. The results of our paper can be capitalised in community studies or comparative studies in time and space, or they can be included

in a cluster of statistical data to rethink and reshape policies for the transition to green energy.

As regards the structure of this paper, the introduction briefly describes the theme of the research, the key concepts integrated into the body of the work, the purpose, and the scientific content. In the section Theoretical background, a review of the scientific literature on the topic is carried out. Section Research methodology describes the methodology of the research and the main objectives targeted, the next section refers to the description of the scientific approach and the main results of the research carried out, and last section presents a set of conclusions in the light of the results obtained from the research carried out.

1. Theoretical background

In the scientific literature, most often, the term "low consumption" is associated with that of poverty, a difficult and defiant problem for many states of the planet (Dercon & Luc, 2011; Hallegatte & Rozenberg, 2017; Krishna, 2004; Martin et al., 2020; Olson Lanjown & Lanjown, 2001; Ravallion, 2014; Schwalb et al., 2023). The economic and social reality confirms this phrase: a limited capacity of aspiration to well-being is unanimously equivalent to the population's low access to food, housing, drinking water, sanitation, energy or education and health services (Emerick et al., 2016; Kaidi & Mensi 2019; Sun et al., 2022).

The low standard of living is directly influenced by the degree of development of a state and the average income per family or per inhabitant (Harrison, 2007; Narain et al., 2008; Wang et al., 2023; Zhang et al., 2023). The present study focuses on Romania. According to The World Bank (2022), in a world ranking of GDP per capita for 190 states, Romania was in the 61st position with USD 15,619 per inhabitant; this was above the world average of USD 12,263 per capita but well below the average of the European Union, which was for the same period at the level of USD 37,280 per capita.

Contemporary society is facing a series of interconnected manifestations (pandemics, economic crises, devastating natural phenomena, reduced availability of resources), one of the main causes being represented by the long promotion of unsustainable production and consumption systems, of an intensely globalised and insufficiently harmonised economy (Kuc-Czarnecka et al., 2023; Lazaric & Toumi, 2022). The diversification of energy production sources and the reduction of its consumption is one of the directions of action contained in the UN strategy to change the image of the world in the next two decades (De Oliveira & Oliveira, 2023; Gebara & Laurent, 2023).

Sustainable Development Goal 7 (SDG7) – affordable, reliable, sustainable and modern energy for all by 2030 aims to reduce economies' unsustainable and harmful dependence on fossil fuels and implement new energy solutions that neutralise climate change (Anwar et al., 2022; Elavarasan et al., 2023; Toukabri & Youssef, 2022).

With the adoption of the European Green Deal and the Green Generation or RePowerEU agreements, the transition to green energy has become a necessary step towards reducing the EU's energy dependencies (European Commission, 2023) on external suppliers. Although in recent years, the signing of the UN SDG agreement is paying increasing attention to the analysis of energy consumption at the level of household consumers and its impact on the environment, it should be noted that there is a lot of particularly valuable research carried out well before 2015, with excellent results and practical applicability, which emphasise the correlations between the factors of influence on energy consumption at the residential level and the effects on the environment (Abrahamse et al., 2005; Brandon & Lewis, 1999; Greening et al., 2000; Poortinga et al., 2004; Steemers & Young Yun, 2009).

The general and specific factors that influence the energy consumption policies at the national level, and in particular at the residential level, differ greatly from one nation to another and even within the same state, depending on the given conjunctural context. Studying the specialised literature in the field of energy consumption at the residential level, the authors came to the conclusion that the higher the segmentation of the research topic, the more the specificity of the conclusions increases. To capitalise on the research results of as many studies and experiences as possible, it is recommended not to compare certain phenomena and processes that take place in the case of a different context from the one used as a model.

Many factors have been discovered to influence household energy-saving habits, which can be grouped into three primary sources:

individual characteristics, external influencing variables, and intentions to save energy (Reiss & White, 2006; Wang et al., 2023; Zhang et al., 2023). Individual characteristic factors can be divided into objective and subjective characteristics. Gender, age, income, and educational background are examples of socio-demographic traits (Alibeli & Johnson, 2009; Frederiks et al., 2015; Palani et al., 2023; Schwepker & Cornwell, 1991).

Most authors consider that age is an important influencing factor for many decisions, but correlations between energy saving and consumption are insufficiently studied; some conclusions (Estiri & Zgheni, 2019) show that with age, up to 55 years, energy consumption increases because increase in the number of family members requires large households and superior material needs. Among the elderly population, there is often a lower level of energy consumption, which is linked to behavioural aspects and household status (Wang et al., 2023; Yagita et al., 2021).

Analysing the importance of income and the impact of various socio-economic, behavioral and physical factors on energy efficiency and energy consumption at the residential level, Kumar et al. (2023) consider that sustained efforts are needed to understand better the correlations between attitudes towards consumption and directions of action aimed at energy conservation and the study of human behavior must be part of intervention strategies at the national and regional level.

Many authors, quoted by Baltruszewicz et al. (2023), think that there are significant inequalities in the distribution of energy consumption and that the population with high well-being is the main user of energy because sophisticated needs require high consumption (Darby and Fawcett, 2018; Gough, 2017; Wiedmann et al., 2020) while many households consume so little energy that they cannot achieve a satisfactory level of well-being (Ivanova et al., 2017; Kikstra et al., 2021).

According to Poortinga et al. (2004), academic background is highly associated with energy-saving behaviors and is strongly correlated with the adoption of various energy-saving solutions. As higher education occupants were more likely to be environmentally aware, the increase in education level is one of the most effective policies. As several years are necessary to increase the education level in a country, this measure will have mainly long-term and not immediate effects (Vogiatzi et al., 2018). The impacts of individual objective characteristics on energy-saving behavior are diverse and no consensus has been reached for some variables, probably due to the differences in empirical contexts and data (Zhang et al., 2019). Previous research has shown that respondent age, gender, educational background, income level, and marital status all influence individual energy-saving practices (Han & Cudjoe, 2020). Piao and Managi (2023), in a study on life satisfaction in 37 countries, believe that buying energy-saving household products has a more limited effect on energy consumption expenditure compared to energy-saving behavior.

In the most recent Plan of European measures (February 2023) aimed at reducing consumption and the transition to green energy (RePowerEU), it is stipulated that special attention should be paid to strategies to adapt the behavior of household consumers to new trends, noting that the adoption of sustainable solutions anchored in the reality of each state, could lead to a decrease in the consumption of this segment even by up to 20% compared to the present moment (European Commission, 2023). In this context, it is interesting to analyse some factors that can influence the energy-saving behavior of the Romanian consumer, given that Romania is a country with a consumption per family located at the lower limit of the European Union states.

Starting from the fact that in the ex-communist bloc, in Central and Eastern Europe, such an approach has not yet been achieved, most authors developing behavioral studies and regressional analyses in provinces of China, African countries, Arab states or developed countries, where conditions and perceptions regarding energy consumption are specific, the authors considered this paper an important starting point in the process of evaluating the behavior of the population in an ex-communist state, which could be extended to other countries with a similar past. The results are useful to understand the typology of residential consumers from the perspective of their sensitivity to energy problems as well as their willingness to adopt some voluntary energy-saving measures.

In the current geo-political and strategic context, this paper is a continuation of the authors'

research in the field of information analysis on SDG7 and the involvement of household consumers in adopting the most efficient measures for reducing energy consumption and transition to green energy (Stancu et al., 2023).

Based on the theoretical background, our research aimed to know the influence of some socio-demographic factors on the intention to adopt voluntary measures to reduce electricity consumption in the context of sustainable development measures.

The following research objectives have been established, with the related hypotheses:

RO1: Identify the extent to which the socio-demographic factors (age, income, education) determine changes in the consumption behavior at the residential level in the context of intensifying national and international discussions on the energy crisis and the achievement of the strategic sustainable development goals (SDG7).

H1: Socio-demographic factors (age, income, level of education) exert a significant influence on the adoption of voluntary measures to reduce energy consumption.

RO2: Assessment of the influence of income and information level on the perception of national macroeconomic measures to reduce energy consumption and targets imposed by the European Union in the light of UN strategies.

H2: The perception of the government's measure to increase electricity prices is significantly influenced by income and level of information and is predominantly negative.

2. Research methodology

The research consisted of a quantitative survey based on a questionnaire. Methods specific to deductive statistical analysis were used for testing the research hypotheses. The cause and effect links and their significance level were identified and tested using SPSS under Windows (descriptive statistics and correlation methods). Central trend indicators (mean and median scores) were used, as well as vaulting and asymmetry indicators. To find if the difference between the responses of two groups is statistically significant or not, a two-sample *t*-test was performed. Similar methods were found in the literature, when influence of factors determining consumer-saving behaviour was analysed (Boomsma et al., 2019).

The data used in this research is the result of processing the valid answers obtained to the questions formulated by the authors in a questionnaire, distributed through the Google Forms platform. For sampling, the convenience sampling technique (a non-probability sampling method) was used, in which units are chosen for participation in the sample due to their being the most accessible to the researcher. A total of 902 individuals provided answers to the 22 questions designed to identify a possible consumer electricity pattern, as well as to estimate their potential willingness to adapt to new global trends in energy consumption and diversification. The questionnaire was addressed to students, teaching staff and non-teaching staff of the Academy of Economic Studies in Bucharest, where the authors work, to groups of people from the social environment close to the authors as well as to the general public (between May and June 2023). The response rate to the questionnaire was about 55%, and the questionnaire was addressed to a total of 1,690 subjects.

The structured questionnaire contains sections that include 22 questions, of which 20 are closed and 2 are open. A five-point Likert scale (from 1 – strongly disagree to 5 – strongly agree) and semantic differential were used. The questions referred to the socio-demographic distribution (age group, gender, level of education, income level, family size, civil status, occupational status) and knowledge and attitude regarding the reduction of energy consumption, general consumption behaviour and the sources of electricity consumption.

The first stage of this research was the analysis of the consistency and reliability of the constructed questionnaire. In this regard, we estimated Cronbach's alpha coefficient. According to the author, it is estimated that the threshold of 0.7 is an indication that measurements were made consistently. The coefficient value (0.87) confirmed the internal consistency of the scale used (Tab. 1).

The estimation of this coefficient involved the use of the following formula for calculation:

$$\alpha = \frac{N * \overline{cov}}{\overline{var} + (N - 1) * \overline{cov}} \quad (1)$$

where: N – the number of items included in the analysis; $\overline{cov}$ – the average covariance of the items included in the analysis; $\overline{var}$ – the average variance of the items included in the analysis.

Tab. 1: The results of the estimation of Cronbach's alpha coefficient

Cronbach's alpha	Cronbach's alpha (based on standardised items)
0.87999	0.89029

Source: own

Tab. 2: The socio-demographic characteristics of the respondents

Socio-demographics	Frequencies	Percentage (%)
Gender		
Women	586	65.0
Men	316	35.0
Age (years)		
18–25		75.0
26–35		7.0
36–45		7.0
46–55		9.0
Above 55		2.0
Marital status		
Unmarried		80.0
Others		20.0
Education		
Higher education		81.4
High education		7.2
Secondary and primary education		0.4
Monthly average income per capita (EUR)		
Below 400		34.0
401–800		18.0
801–1,200		9.0
1,201–1,600		33.0
Above 1,600		6.0
Employing status		
Employee (part-time or full-time)		81.4
Others		8.6

Source: own

Following the pre-processing stages of the data, out of the 902 completed questionnaires, 865 questionnaires were validated. From a socio-economic point of view, the structure of the respondents is described in Tab. 2.

3. Results and discussion

Most of the respondents believe that at the household level, there is a fairly high possibility of reducing electricity consumption. About 34.6% of respondents estimated that

they can reduce consumption by up to 10%, while 29.9% of individuals believe that they could ensure a reduction in consumption of between 10% and 20%.

From the perspective of adopting clear measures to reduce consumption, the majority of respondents say that they have purchased electrical equipment with the A+ energy label (about 51.3%). The second most popular measure adopted among households is thermal insulation of dwellings. At a rate of 11.9%, the respondents say that they have installed solar panels within the household to streamline electricity consumption and diversify the sources. The second stage of the analysis process was related to the research objectives, using various descriptive metrics and statistical methods to test the significance.

The results of the research revealed the existence of differences in perception between age segments (Fig. 1). The predominant group, represented by respondents aged 18–24 years, recorded an almost equal distribution of opinions among the three savings thresholds presented in the content of the question in the questionnaire (up to 10%, 10–20%, and 21–30%). Respondents in the 25–34 years old segment tend to believe that the reduction can be made especially in the range of 0–20%, family life demanding a higher electricity consumption, justified by the nature of more complex activities and by the diversity of functional appliances. The 45–54 years old segment considers in a larger percentage that the reduction could reach 21–30%.

The age group over 65 years believes that, due to low incomes, the consumption of electricity and heating agents is already very well controlled so that the annual savings can reach an increase of up to 10%. 33% of the respondents segment consider that, being single persons, they can reduce the consumption by 21–30% as a result of less intense routine household activities and of the important time spent at other residences than the permanent one (e.g., of sons, cohabitation partners).

Next, in order to identify the impact of social and demographic factors on the quality of life and energy consumption behavior, we tested two indicators considered relevant in the literature: consumption associated with income and education levels. In the first case, regarding

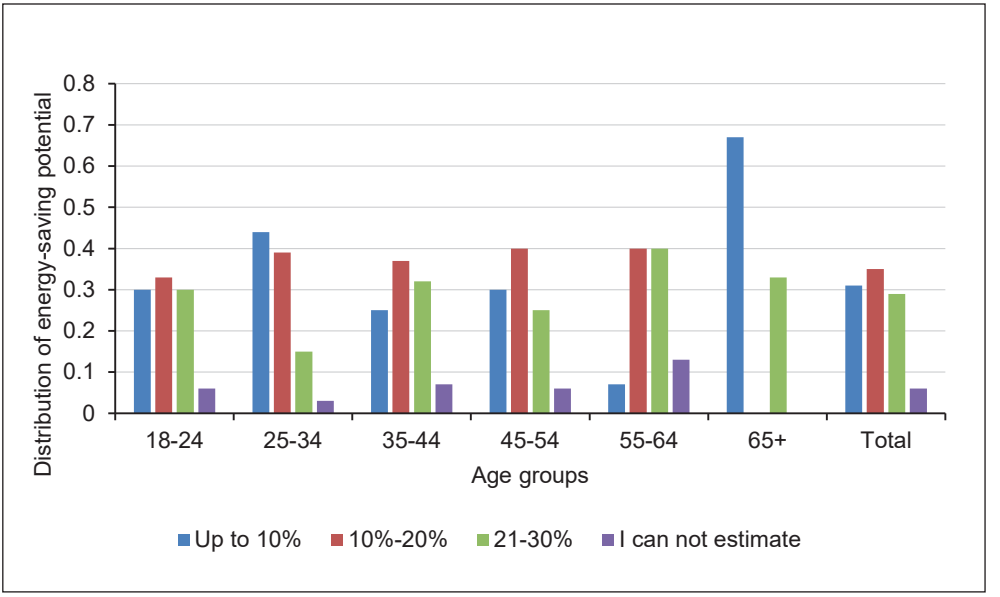

Fig. 1: Energy-saving potential relative to the age group

Source: own

the analysis of the consumption behavior according to the income, the respondents were divided into two groups:

- N1: Respondents with a source of income: employees, freelancers, retirees;
- N2: Respondents without a source of income: students, unemployed.

To see if there are significant differences in the attitude towards energy consumption between the two groups, we applied the *t*-student test for variation, for 4 of the voluntary measures to reduce energy consumption included in the population opinion survey questionnaire: the purchase of smart devices for consumption management, the arrangement of solar panels, the purchase of electrical equipment and appliances with the A+ label, thermal insulation of dwellings (Tab. 3).

Tab. 3: Two-samples for variances test

	INT_DEV (N1)	INT_DEV (N2)	Panels (N1)	Panels (N2)
Mean	0.32546	0.25413	0.11024	0.12397
Variance	0.22011	0.18994	0.09834	0.10882
Observations	381	484	381	484
df	380	483	380	483
F	1.15885		0.90368	
***P* (*F* ≤ *f*)**	0.06338		0.14973	
$F_{critical}$	1.17211		0.85166	
	Energy class A (N1)	**Energy class A (N2)**	**Insulation (N1)**	**Insulation (N2)**
Mean	0.61155	0.42355	0.55906	0.43595
Variance	0.23818	0.24466	0.24716	0.24641
Observations	381	484	381	484
df	380	483	380	483
F	0.97352		1.00306	
***P* (*F* ≤ *f*)**	0.39258		0.48589	
$F_{critical}$	0.85166		1.17211	

Note: Int_DEV – interval of deviation (confidence interval).

Source: own

It is noted that in neither of the four situations was the $F_{calculated}$ smaller than $F_{critical}$ – meaning that there are no significant differences between groups, which means that the null hypothesis referring to the fact that there are no significant differences between the two groups of respondents will be accepted.

Along with the average income, another important feature is the level of education. Thus, depending on the most recent form of graduated education, we have created two other segments of respondents:

- N1: Respondents with secondary education: gymnasium, high school;
- N2: Respondents with higher education: bachelor's, master's, doctoral.

From the summary descriptive statistics, we note that in respondents with higher education, the average associated with the intensity of knowledge of the importance of measures to reduce energy consumption and the transition to the green economy was higher than the average belonging to respondents who do not have university education (Tab. 4),

Tab. 4: Level of importance given to measures to reduce consumption, depending on the level of education

Education level	Average	Median	Standard deviation	Asymmetry	Vaulting
Medium	3.835	4	1.12	−0.64	−0.385
High	4.011	4	1.18	−1.12	0.450

Source: own

respectively 4.001 compared to 3.835 (score on a scale from 1 to 5).

Introducing the vaulting coefficient in the analysis, which will show us the shape of the distribution, we notice that for those respondents with higher education, the curve will be slightly leptokurtic, so we will have an excess of frequencies in the central area, while for those with secondary education, the distribution will be platikurtic, so the range of values will be wider, what can be an indication that there are differences between the two groups of respondents.

As for the measures agreed at the European level, perhaps the most important of these was the reduction by 10% of the gross electricity consumption and by 5% of the residential consumption during peak hours. To reach these targets, some of the most common mechanisms have been integrated through the increase in the price of electricity, under the pressure of the current geo-political and economic context. Thus, regarding the level of information and knowledge of the targets imposed by the European Union (codified by the variable EU_RED), only 66 of the respondents (7.6%) consider themselves very familiar with the subject of the European approaches regarding the change of the consumption behavior (Tab. 5).

Tab. 5: Descriptive statistics

Attitudinal	Average	Median	Standard deviation	Max (respondents)	Min (respondents)
EU_RED	2.80	3	1.16	66	154
PRICE_RED	2.75	3	1.20	59	183

Note: EU_RED – the level of information related to energy-saving targets, imposed by EU; PRICE_RED – the attitude towards energy's price rise.

Source: own

The average response was 2.80 (on a scale of 1 to 5). Over 70% of the surveyed segment does not know the content of sustainability policies. The complete distribution is presented in Fig. 2.

As for the strategic measure of price rise, opinions were divided, resulting in a distribution that tends towards a disagreement, with 72% of respondents believing that the action is not at all, very little or less appropriate. When we add the income variable, we find that the distribution increases slightly towards the perception of the appropriate strategic measure; 36% of the respondents with an income of more than EUR 800 (4,000 lei) consider that the measure to increase prices responds to the problems of the energy crisis in the current critical context (Tab. 6).

Therefore, *H2* is partially correct, meaning that income does not significantly influence the perception of energy price increase associated with the reduction of energy consumption, but the level of information does.

Based on the results presented in the previous section, we can observe that age influences the perception of potential consumers to reduce monthly electricity consumption, conditioned by the more efficient use of home appliances.

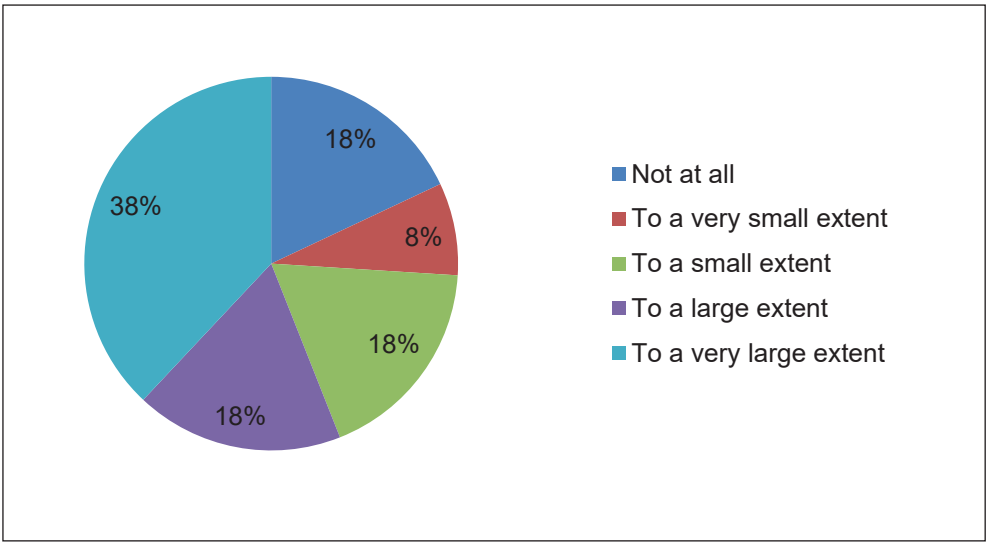

Fig. 2: **Awareness of the EU's energy reduction targets**

Source: own

Tab. 6: **Perception of electricity price increase related to income**

Income	Perception (%)				
	Not at all	To a very little extent	To a little extent	To a great extent	To a very great extent
Income < EUR 800	21	17	36	21	6
Income > EUR 800	25	18	21	27	9

Source: own

Based on previous findings, age could be considered a curtailment energy-saving behaviour, but not always was tested in the case of efficiency behaviour (Karlin et al., 2012). In agreement with the authors cited in the body of the paper (Estiri & Zagheni, 2019; Yagita et al., 2021; Wang et al., 2023), age is a component that impacts energy consumption. In the case of our study, besides the fact that respondents under 50 years of age accept that consumption demand increases with age and family growth, at the same time the concern for energy saving propagates amplified, more than for respondents over 65 years which is already in a long process of adapting its needs to the minimum consumption. At the same time, as evidenced by the research of Frederiks et al. (2015) and Palani et al. (2023), the consumption behavior of the population tends to change over time under the impact of socioeconomic factors, in the case of our study by introducing ecological practices at the family level, such as: checking the energy class of appliances before purchasing, reducing the frequency of use of certain devices or streamlining their operation, thermal insulation of homes, decoupling electrical equipment from the network when leaving home, so that the loss of energy is considerably reduced.

Regarding the classification of respondents by income categories, it is found that there are no significant differences in saving behavior,

so within the group of respondents, the size of the income is not a factor influencing the application of voluntary measures to reduce electricity consumption. However, we must remember that 75% of our respondents are students or very young people, so their income is small and most likely they do not have their own home, so they are determined to purchase their own household appliances and ecological technologies or more, to make changes to the housing structure, which would involve important investments. According to Urban and Ščasný (2012), income has a positive effect on efficiency investments.

Concerning the influence of education level on energy-saving behavior, our results sustain the premise that high education level would lead to the conduct of more energy-saving behaviors (Belaïd & Garcia, 2016; Han & Cudjoe, 2020; Yang et al., 2016), even though there is research stating that formal level of education does not play prominent role concerning domestic energy-saving (Urban & Ščasný, 2012). In contrast to income, the research found that the level of education is a differentiating aspect, with respondents with higher forms of education giving greater importance to sustainable behaviour and being more likely to save energy at home, as was stated also by Vogiatzi et al. (2018). Due to the importance of education in this context, the same authors proposed some educational actions that have a more immediate effect, such as courses in schools about energy use, energy consumption and energy saving.

As regards the price increase associated with the reduction of energy, consumption is perceived as a negative strategic measure, both by the category of high-income and low-income respondents. However, previous research results raised doubt as to the effectiveness of classic price-based interventions in reducing electricity consumption (Werthschulte & Löschel, 2021). At the same time, 70% of the respondents do not have information about the targets set by the world and European forums to reduce electricity consumption. As a result, this aspect will negatively influence the understanding of the necessary macroeconomic measures or the integration of voluntary actions to reduce consumption.

Conclusions

Household energy consumption accounts for an important share of a country's total consumption. The adoption of a set of voluntary measures aimed at reducing energy consumption among the population is the premise for the transition to a new society, in which sustainability will become a unanimously accepted reality. Although numerous researches have been conducted in the literature that have built ideas, generated conclusions and created solutions, it goes without saying that, with the emergence of new challenges and trends, such as the transition to the digital age and the green economy, the profile of the energy consumer will not remain the same over time. The future consumer behaviour will never be similar to that of the past or present, at least because digitalisation will create new needs, devices and equipment and energy sources for consumption will no longer have the same origins as the current ones. That is why the role of studies like the present one is to capture the essence of the moment, to capitalise on it and transform it into medium and long-term social advantages. The acceptance of change in everyone's life and the willingness to be part of this process is influenced by many factors, among which socio-demographic factors play a particularly important role.

From the multiannual statistical data but also from the results of the specialised literature consulted by the authors, it resulted that even up to the moment of triggering the present crises and political conflicts, there were notable differences between nations, from the point of view of residential energy consumption. These differences are clearly associated with numerous factors (geo-strategic, economic, political, social). The level of development of each country and the purchasing power of the population has already shaped a certain consumption behavior, so a radical change of consumption habits, without being associated with reliable directions of action (accessibility to cheaper energy sources, support for financing common objectives, and the education of the population) is unviable.

The research results provide important insights regarding the energy-saving behaviour of Romanian residential consumers (especially young people) and the influence of some socio-demographic factors, but the findings cannot be generalised, due to the size and the structure of the sample. To obtain representative conclusions, future research will improve the sample size and structure and extend the analysis to other categories of residential consumers.

Also, the findings have to be integrated into the larger context of shaping the typology of residential consumers of an ex-communist country from the perspective of their sensitivity to energy problems and their willingness to adopt some voluntary energy-saving measures. Comparison with other studies from other countries of the European Union could lead to a better understanding of which measures are more impactful for inducing energy-saving behavior. A future reasearch direction could be an extended analysis of factors determining energy-saving behaviour at the entire bloc of former communist countries.

In the authors' opinion, the change of consumption behavior must be carried out naturally and with caution, by understanding the benefits and evaluating the costs of opportunity, so that the contemporary world can identify and understand the area of balance resulting from the effort-cause-effect correlation. Consumption habits are shaped in a variable time and have at their origin numerous factors, so that any pressure or amendment of some behaviors considered natural until now, can generate counter-effects and delays in achieving the proposed sustainability objectives.

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Integrity management of e-commerce enterprises from the perspective of co-governance supervision

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Abstract: *The integrity challenges facing e-commerce enterprises are increasingly provoking significant reactions from society. To analyze the dynamic evolution and influence factors of strategies made by the government, e-commerce enterprises, and consumers in different situations, the co-governance supervision of government-e-commerce enterprises-consumers was introduced in this study based on the theory of daily activities. A tripartite evolutionary game model comprising the government, e-commerce enterprises, and consumers was constructed using Matlab for analysis and verification. Results indicate that (1) e-commerce enterprises engage in dishonest practices mainly for additional gains. If the potential benefits obtained are outweighed by the costs of potential sanctions, compensation to consumers, and tarnished reputations under strict government supervision, then e-commerce enterprises are likely to adopt stable integrity management strategies. (2) enhancing government regulation effectiveness and encouraging consumer complaints can significantly reduce the probability of dishonest practices among e-commerce enterprises. (3) increasing government penalties for dishonest practices of e-commerce enterprises, improving government regulations, and engaging in consumers in co-governance by voicing complaints can effectively reduce their motivation for dishonest practices. The conclusions of this study not only enrich the research on integrity management of e-commerce enterprises from the perspective of co-governance supervision, but also provide guidance for curbing dishonest practices by e-commerce enterprises and protecting consumer right.*

Keywords: *Co-governance supervision, e-commerce enterprise, integrity management, evolutionary game.*

JEL Classification: *C73, D79.*

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Introduction

In the rapidly evolving digital landscape, e-commerce has become an important component of modern commercial activities, effortlessly overcoming geographical limitations (Yan, 2020). The United Nations International Trade Center projects that the global e-commerce market will expand from an estimated USD 3.3 trillion in 2022 to USD 5.4 trillion by 2026. This rapid economic growth has resulted in fierce competition among e-commerce enterprises, with many facing integrity issues during their development process. The year 2022 saw a resurgence in consumer spending

post-pandemic, leading to a surge in online consumption complaints. The main concerns predominantly include refunds, product quality, fraud, after-sales service, counterfeit products, misleading promotions, problematic returns and exchanges, and mistaken deliveries. The spatial and temporal separation in e-commerce transactions creates an imbalance between buyers and sellers (Xu & Zhang, 2009). This gap is often exploited by e-commerce enterprises, leading to persistent corporate integrity lapses and a decline in ethical standards within the e-commerce market. Without immediate action to curb these unethical practices, the detrimental behaviors of e-commerce enterprises are likely to spread rapidly (Safaei, 2014). Maintaining integrity in the e-commerce era has thus become a significant challenge. In the practical context of e-commerce, the government and consumers play a crucial role in ensuring the integrity of business operations. The government imposes sanctions and discloses dishonest business practices to protect consumer rights. Conversely, consumers resist dishonest business practices by lodging complaints and refusal to buy, among other measures. However, actual government regulation often falls short of the necessary intensity, and its capabilities are limited, thereby provoking e-commerce enterprises to engage in exploitative practices for considerable gains. The persisting integrity issues within the e-commerce industry highlight the inadequacy of effective legal sanction mechanisms in China, where minor penalties seemingly lack effectiveness (Cai & Rao, 2016). Moreover, consumer awareness about the importance of monitoring the integrity of e-commerce enterprises and protecting their own rights remains largely underdeveloped. In shared responsibility, consumers, as members of civil society, collaborate with government, enterprises, and all other involved actors along supply chains (Karimova et al., 2023).

At present, researchers have made significant contributions to understanding the issue of integrity within e-commerce enterprises, providing a theoretical foundation for this research. Existing theoretical explorations mainly focused on the interaction between enterprises and governments (Jiang et al., 2022; Luo et al., 2022; Pan & Xie, 2021; Wang & Ren, 2020; Zhu et al., 2023). However, these explorations often overlooked the critical role of consumer feedback and its effect on curbing corporate dishonesty. Conversely, some scholars realized the essential role of consumers in maintaining e-commerce integrity (Wang & Ren, 2021; Wang & Zheng, 2022; Zhang et al., 2020b). However, the literature still demands further exploration into effective strategies for enhancing integrity management between e-commerce enterprises and their consumers. Some scholars established game theoretical models incorporating government, e-commerce enterprises, and consumers to study related issues (Lei et al., 2021; Yang et al., 2017). However, these studies relied on pairwise game theories, missing a comprehensive analysis within a unified framework that considers all parties influencing corporate integrity practices concurrently. Despite these insightful explorations into e-commerce enterprise integrity, a few studies examine the issues only considering a single government regulation, resulting in a lack of systematic research in the area of e-commerce enterprise integrity supervision. According to the theory of daily activities, analyzing daily activities requires a systematic and comprehensive consideration from three aspects: motivation, opportunity, and control (Chang et al., 2020). In this context, “motivation” refers to the reasons e-commerce enterprises engage in dishonest practices; “opportunity” refers to the performance of e-commerce enterprises in dishonest practices; and “control methods” refers to administrative supervision from the government, together with market feedback and consumer supervision. This theoretical framework can be used to systematically analyze the dishonest practices of e-commerce enterprises and the interplay between e-commerce enterprises, the government, and consumers from the perspective of co-governance supervision. This approach changes the discourse of e-commerce integrity governance from a singular government regulation to multiparty collaborative governance involving consumer participation, making it more systematic. In this study, a tripartite evolutionary game model involving the government, e-commerce enterprises, and consumers was constructed to analyze the dynamic evolution and influence factors of strategies made by the three parties in different situations.

The marginal contributions of this study are mainly reflected in the following aspects. Firstly, the study aimed to construct a governance system involving the government and consumers

using the theory of daily activities and co-governance, thereby further enriching the theoretical base for e-commerce integrity supervision. Secondly, a tripartite evolutionary game model was constructed by including consumers in the dynamic interplay between the government and e-commerce enterprises. This study serves as a practical guide for the government and consumers to jointly supervise and manage integrity issues in e-commerce enterprises.

The remainder of this study is organized as follows. Section 1 provides a summary of the literature review. Section 2 delves into the problem description and model construction, proposing assumptions and creating a tripartite evolutionary game model involving the government, e-commerce enterprises, and consumers. Section 3 presents a stability analysis and simulation, establishing replicator dynamic equations, and Jacobian matrices for stability assessment under different conditions. Section 3 deals with of conducting and discussing simulation analysis via Matlab. The last section presents the conclusions and implications.

1. Theoretical background

Relevant theoretical studies focused on the causes of dishonest management practices within e-commerce enterprises, the need for integrity management, the integrity construction process, the evaluation standard for assessing integrity, and supervision of integrity.

In terms of the lack of integrity in e-commerce enterprises, some scholars reported that online fraud, product quality, after-sales service, and transaction information leakage are the main manifestations of the lack of integrity in e-commerce enterprises. Researchers indicated that strengthening industry self-discipline, establishing a sound credit evaluation system, and improving e-commerce-related laws and regulations, e-commerce enterprises can consciously uphold their integrity obligations and ensure e-commerce development in terms of the necessity of integrity in e-commerce enterprises (Qiu, 2008; Wei, 2009; Zhao & Yu, 2011). To entice consumers to purchase products and services, e-commerce enterprises need to eliminate customer security concerns during the transaction process (Wei, 2011). Similarly, the integrity practices of e-commerce enterprises can convey a positive impression to customers, in turn increasing their trust and enhancing their willingness to make online purchases (Kwon & Lee, 2014; Oliveira et al., 2017). Rajesh (2023) considers the economic, environmental, and social dimensions of sustainability, with utilitarian theory as the center, and points out that corporate integrity behavior and any improvement in social responsibility activities can bring about social welfare while providing them with sustainable competitive advantages. Salvatore et al. (2022) focused on the communication of corporate social responsibility through social media and its relationship with sustainable development goals. The importance of adhering to the principle of integrity, establishing mutually beneficial agreements with stakeholders, and promoting value creation and social well-being through ethical marketing should be emphasized. Incorporating integrity principles into corporate strategies can enhance reputation and contribute to social progress (Chong & Patwa, 2023). From a different perspective, a significantly negative correlation exists between corporate integrity and internal control deficiencies. Corporate integrity can improve product control quality (Shu et al., 2018). In summary, the integrity of e-commerce enterprises is an important factor affecting the consumer experience in e-commerce. At the same time, e-commerce enterprises adhering to an honest management approach can enhance consumer trust and their own credibility.

Regarding the framework for building integrity and the criteria for its evaluation, multiple facets contribute to the formation of corporate integrity, including corporate culture, corporate integrity system, integrity supervision, and credit repair (Ma, 2019). The construction of corporate integrity can use systems as a constraining factor for business operations, thereby increasing the repercussions for dishonest behaviors. The anticipated objectives of corporate integrity can also be attained by fostering a culture of integrity between enterprises and their personnel (Xu, 2020). Scholars established a model for analyzing the online reputation system of e-commerce enterprises using a combination of mixed-gaming and agent-based simulation. The research examined how different behaviors of buyers and sellers affect e-commerce policies (Aringhieri et al., 2018). The evaluation and management of e-commerce integrity is a focal point within e-commerce research. Scholars used methods such as analytic hierarchy process, fuzzy analytic hierarchy process, and

intuitionistic fuzzy analytic hierarchy process to devise models for evaluating the integrity of e-commerce enterprises (Huo & Yang, 2017). The evaluations of corporate integrity can be divided into internal and external credit evaluations, with the criteria encompassing the quality of the enterprises, personnel management, and perceptions held by employers (Zhang et al., 2020a).

Scholars turned their focus to the area of integrity regulation within e-commerce. Some researchers observed that e-commerce regulation has fundamentally transformed, indicating that existing regulatory paradigms grounded in the traditional economy and legal frameworks fall short and are unsustainable. Moreover, new governance models and methods that adapt to the development of the e-commerce market have yet to be established (Chai, 2017; Xue & Zhao, 2019). Some scholars also voiced the complexities faced by current e-commerce regulation from multiple perspectives, such as intellectual property (Hu & Ma, 2019; Zheng, 2017) and quality supervision (Chen, 2019; Lu & Ni, 2017). A regulatory framework can integrate government agencies to reinforce the authority and balance of e-commerce regulations, thereby promoting fairness in transactions between buyers and sellers (Wang, 2014). Zhang et al. (2022) used the game theory to analyze the formation of integrity risks in e-commerce, proposing that governmental steering through legislation and taxation can enhance societal welfare. Shen et al. (2021) reported that forceful supervision and penalties by the government can deter corporate misdemeanors, emphasizing that consumer support is crucial for improving regulatory effectiveness. However, the intricate and high-tech nature of the e-commerce industry often veils corporate integrity operations, confronting regulators and law enforcement with challenges due to their limited digital expertise, impeding prompt and efficient action against illegal corporate conduct (Huang & Gu, 2016). Furthermore, the concept of co-governance supervision is gaining traction, advocating for the joint supervision of social issues by various entities, including the government. This model combines the administrative power exercised by the government with the private rights exercised by social entities, thereby transforming the single government supervision to a joint supervision of multiple entities. Co-governance supervision has a positive effect on improving the efficiency of government governance and saving governance costs, making it an effective regulatory model (Gao, 2019). The collaborative supervision model of multiple entities, including industry associations, e-commerce trading platforms, and the public, can compensate for the shortcomings in government direct supervision and improve regulatory effectiveness (Lu & He, 2019). Wang and Ren (2020) explored how strengthening government supervision can solve the regulatory difficulties in market credit within the internal supervision mechanisms by developing an evolutionary model involving merchants, platforms, and governments. Meanwhile, the role of consumer feedback mechanisms should be enhanced, and consumers should have avenues to report e-commerce issues to authorities (Bakos & Dellarocas, 2011). Garcia et al. (2022) considered the dynamic choices of consumers and their opinions on corporate ethics in their research. Souiden et al. (2022) proposed that consumers' perception of a firm's liability has a significant impact on their feeling of culpability, which in turn affects their perception of firm's corporate social responsibility and reputation. In addition, consumer awareness of corporate social responsibility and integrity plays an important role in regulating and offsetting the ultimate impact of corporate public relations crises. The legislative action to manage often-misrepresented consumer feedback and seek balance between public intervention and market mechanisms is necessary (Ying, 2018). On the topic of third-party institutions, which are rapidly emerging within the e-commerce industry, Cheung et al. (2018) analyzed the importance of developing legal protections for the reputations of online businesses.

Current research indicated that e-commerce enterprises face inherent challenges in maintaining integrity due to their profit-oriented nature. The existing literature mostly focused on the influencing factors of integrity management of these enterprises, the development of integrity evaluation standards, and corresponding suggestions. It is widely acknowledged that key actors in the integrity supervision of e-commerce enterprises include governments, e-commerce platforms, and consumers, with their collaborative supervision being crucial in promoting the healthy development of the entire e-commerce industry. Although existing research offered valuable insights for addressing ethical lapses within e-commerce,

it still exhibits notable gaps. On the one hand, investigations on the motivating influence these key entities have on consumers remain lacking, even though consumers are at the endpoint of e-commerce. On the other hand, the potential of co-governance regulation to address integrity issues within e-commerce has not been adequately examined by scholars. Drawing from the diversified governance strategy in the environmental governance model (Chen, 2020), a shift from a single government regulation to a multiparty joint supervision with consumer participation was suggested in this study. To effectively regulate the dishonest practices of e-commerce enterprises, the government should enact policies that steer and harness the power of consumer participation in co-governance supervision, thereby optimizing regulatory effectiveness. Therefore, this study analyzed the dishonest practices of e-commerce enterprises from the perspective of daily activity theory. A tripartite evolutionary game model was also established. This model encapsulates the government, e-commerce enterprises, and consumers under the joint governance and supervision model of the government and consumers. Investigating the strategic interactions among three parties, the model seeks to provide a robust theoretical foundation for resolving the integrity challenges faced by e-commerce enterprises under joint governance and supervision.

2. Research methodology

The model was constructed according to the three elements of opportunity, motivation, and control methods based on the theory of daily activities. Opportunity refers to favorable temporal conditions, explaining why e-commerce enterprises can engage in dishonest practices. Motivation is the psychological inclination or internal driving force that stimulates and maintains the actions of an organism and directs them toward a certain goal, explaining why e-commerce enterprises seek to operate dishonestly. The control method essentially involves ensuring work is performed according to established plans, standards, and methods; it helps identify deviations, analyze reasons, and make suitable amendments to ensure the achievement of organizational goals, thereby protecting consumers from any harm caused by opportunities and motivations (Chang et al., 2020).

To solve the problem of lack of integrity in e-commerce enterprises, the target of opportunities is the consumers, the main motivation is e-commerce enterprises, and the control methods mainly come from the government. Given the fact that all three parties are bounded rational groups, a tripartite evolutionary game model is constructed for discussion. The theory of daily activities assumes that the motivation for e-commerce enterprises to engage in dishonest practices comes from high economic benefits. Therefore, in the model, the cost of integrity practices is higher than that of dishonest practices. Opportunities are reflected in whether consumers are willing or capable of transmitting information to regulatory agencies through co-governance regulation. Control methods mainly come from the government. Traditional regulatory efficiency relies on the government's regulatory capacity, whereas under co-governance regulation, the government can explore new regulatory methods by leveraging the active participation of consumers.

2.1 Model assumption and formulation

On the basis of the actual situation of the government, e-commerce enterprises, and consumers, the following assumptions are made: first, the government, e-commerce enterprises, and consumers are all of bounded rationality. Second, the strategy choice space for the government (strict supervision, loose supervision); that for e-commerce enterprises (integrity management, dishonesty management); and that for consumers (complaint, no complaint). The relevant parameters and instructions are shown in Tab. 1.

Based on the relevant parameters in Tab. 1, the tripartite evolutionary game model was formulated as shown in Tab. 2.

Tab. 1: Relevant parameters and instructions – Part 1

Symbol	Meaning	Symbol	Meaning
C_1	Cost spent in integrity management of e-commerce enterprises	U_1	Utility obtained by consumers in case of integrity management of e-commerce enterprises

Tab. 1: Relevant parameters and instructions – Part 2

Symbol	Meaning	Symbol	Meaning
C_2	Cost spent in dishonesty management of e-commerce enterprises	U_2	Utility acquired by consumers in case of dishonesty management of e-commerce enterprises
R	Operating income of e-commerce enterprises	B_0	Compensation made to consumers after dishonesty management of e-commerce enterprises
B_1	Reputation and market loss brought by dishonesty management to e-commerce enterprises	P_1	Success probability of government supervision
C_3	Cost spent in strict government supervision of e-commerce enterprises	P_2	Probability for consumers to found dishonesty management of e-commerce enterprises and succeed in complaints
F_1	Penalties posed by the government to enterprises with dishonesty management	x	Probability of strict government supervision
B_2	Social losses caused by inadequate government supervision	y	Probability of integrity management of e-commerce enterprises
B_3	Credibility brought by government supervision of e-commerce enterprises to the government	z	Probability of consumer complaints
C_0	Cost of consumer complaints		

Source: own

Tab. 2: Pay-off matrix of tripartite evolutionary game

Strategy choice of tripartite subjects		Government revenue	Revenue of e-commerce enterprises	Revenue of consumers
Integrity management (y) and complaint (z)	Strict supervision (x)	$-C_3 + B_3$	$R - C_1$	$U_1 - P_2C_0$
	Loose supervision ($1 - x$)	0	$R - C_1$	$U_1 - P_2C_0$
Dishonesty management ($1 - y$) and complaint (z)	Strict supervision (x)	$-C_3 + P_1F_1 + B_3$	$R - C_2 - P_1(F_1 + B_1) - P_2B_0$	$U_2 + P_2(B_0 - C_0)$
	Loose supervision ($1 - x$)	$-B_2$	$R - C_2$	$U_2 - P_2C_0$
Integrity management (y) and no complaint ($1 - z$)	Strict supervision (x)	$-C_3 + B_3$	$R - C_1$	U_1
	Loose supervision ($1 - x$)	0	$R - C_1$	U_1
Dishonesty management ($1 - y$) and no complaint ($1 - z$)	Strict supervision (x)	$-C_3 + P_1F_1 + B_3$	$R - C_2 - P_1(F_1 + B_1)$	U_2
	Loose supervision ($1 - x$)	$-B_2$	$R - C_2$	U_2

Source: own

2.2 Model analysis

E_{11} is set as the expected revenue of the government when choosing the "strict supervision" strategy, E_{12} as the expected revenue of the government when choosing the "loose supervision" strategy, and E_1 as the average expected revenue:

$$E_{11} = (-C_3 + B_3)yz + (-C_3 + P_1F_1 + B_3)(1-y)z + (-C_3 + B_3)y(1-z) + \\ + (-C_3 + P_1F_1 + B_3)(1-y)(1-z) = -C_3 + P_1F_1 - B_3 - P_1F_1y \quad (1)$$

$$E_{12} = -B_2(1-y)z - B_2(1-y)(1-z) = -B_2(1-y) \quad (2)$$

$$E_1 = xE_{11} + (1-x)E_{12} \quad (3)$$

E_{21} is set as the expected revenue of e-commerce enterprises when choosing the "integrity management" strategy, E_{22} as the expected revenue of e-commerce enterprises when choosing the "dishonesty management" strategy, and E_2 as the average expected revenue:

$$E_{21} = (R - C_1)xz + (R - C_1)(1-x)z + (R - C_1)x(1-z) + (R - C_1)(1-x)(1-z) = R - C_1 \quad (4)$$

$$E_{22} = [R - C_2 - P_1(F_1 + B_1) - P_2B_0]xz + (R - C_2)(1-x)z + [R - C_2 - P_1(F_1 + B_1)]x(1-z) + \\ + (R - C_2)(1-x)(1-z) = -P_2B_0xz - (P_1B_1 + P_1F_1)x + R - C_2 \quad (5)$$

$$E_2 = yE_{21} + (1-y)E_{22} \quad (6)$$

E_{31} is set as the expected revenue of consumers when choosing the "complaining" strategy, E_{32} as the expected revenue of consumers when choosing the strategy of "not complaining," and E_3 as the average expected revenue.

$$E_{31} = (U_1 - P_2C_0)xy + [U_2 + P_2(B_0 - C_0)]x(1-y) + (U_1 - P_2C_0)(1-x)y + \\ + (U_2 - P_2C_0)(1-x)(1-y) = U_2 + P_2B_0x - P_2B_0xy - P_2C_0 + U_1y - U_2y \quad (7)$$

$$E_{32} = U_1xy + U_2x(1-y) + U_1(1-x)y + U_2(1-x)(1-y) = U_1y + U_2(1-y) \quad (8)$$

$$E_3 = zE_{31} + (1-z)E_{32} \quad (9)$$

The replicator dynamics equation of the government is:

$$\mathrm{F}(x) = \frac{dx}{dt} = (E_{11} - E_1)x = x(1-x)(-C_3 + B_3 + B_2 + P_1F_1 - B_2y - P_1F_1y) \quad (10)$$

The replicator dynamics equation of e-commerce enterprises is:

$$\mathrm{F}(y) = \frac{dy}{dt} = (E_{21} - \mathrm{E}_2)y = y(1-y)[-C_1 + P_2B_0xz + (P_1B_1 + P_1F_1)x + C_2] \quad (11)$$

The replicator dynamics equation of consumers is:

$$\mathrm{F}(z) = \frac{dz}{dt} = (E_{31} - E_3)z = z(1-z)(-P_2C_0 + P_2B_0\mathrm{x} - P_2B_0xy) \quad (12)$$

The replicator dynamics system of the government, e-commerce enterprises, and consumers is obtained as follows:

$$\begin{cases} \mathrm{F}(x) = \frac{dx}{dt} = (E_{11} - E_1)x = x(1-x)(-C_3 + B_3 + B_2 + P_1F_1 - B_2y - P_1F_1y) \\ \mathrm{F}(y) = \frac{dy}{dt} = (E_{21} - \mathrm{E}_2)y = y(1-y)[-C_1 + P_2B_0xz + (P_1B_1 + P_1F_1)x + C_2] \\ \mathrm{F}(z) = \frac{dz}{dt} = (E_{31} - E_3)z = z(1-z)(-P_2C_0 + P_2B_0\mathrm{x} - P_2B_0xy) \end{cases} \quad (13)$$

In the game process, all subjects do not know whether their own strategies are the optimal due to the information asymmetry among the three game parties. Thus, they have to continuously adjust their own strategies by observing those of the counterparties in the game process, finally reaching an equilibrium state. According to the theory of evolutionary game, the stability analysis of their strategy choices is hereby implemented.

Asymptotic stability analysis of the government:

$$\frac{d\mathrm{F}(x)}{dt} = (1-2x)(-C_3 + B_3 + B_2 + P_1F_1 - B_2y - P_1F_1y) \tag{14}$$

$-C_3 + B_3 + B_2 + P_1F_1 - B_2y - P_1F_1y = 0$ is a stable demarcation line.

When $-C_3 + B_3 + B_2 + P_1F_1 - B_2y - P_1F_1y > 0$, i.e., $y < \frac{-C_3 + B_3 + B_2 + P_1F_1}{P_1F_1 + B_2}$,

$\frac{d\mathrm{F}(x)}{dx}|_{x=0} > 0$, $\frac{d\mathrm{F}(x)}{dx}|_{x=1} < 0$, $x = 1$ is a equilibrium point. For the government, strict supervision is a stable strategy.

When $-C_3 + B_3 + B_2 + P_1F_1 - B_2y - P_1F_1y < 0$, i.e., $y > \frac{-C_3 + B_3 + B_2 + P_1F_1}{P_1F_1 + B_2}$,

$\frac{d\mathrm{F}(x)}{dx}|_{x=0} < 0$, $\frac{d\mathrm{F}(x)}{dx}|_{x=1} > 0$, $x = 0$ is a equilibrium point. For the government, loose supervision is a stable strategy.

Asymptotic stability analysis of e-commerce enterprises:

$$\frac{d\mathrm{F}(y)}{dt} = (1-2y)[-C_1 + P_2B_0xz + (P_1B_1 + P_1F_1)x + C_2] \tag{15}$$

$-C_1 + P_2B_0xz + (P_1B_1 + P_1F_1)x + C_2 = 0$ is a stable demarcation line.

When $-C_1 + P_2B_0xz + (P_1B_1 + P_1F_1)x + C_2 > 0$, i.e., $x > \frac{C_1 - C_2 - P_2B_0z}{P_1B_1 + P_1F_1}$,

$\frac{d\mathrm{F}(y)}{dy}|_{y=0} > 0$, $\frac{d\mathrm{F}(y)}{dy}|_{y=1} < 0$, $y = 1$ is a equilibrium point. For e-commerce enterprises, integrity management is a stable strategy in this case.

When $-C_1 + P_2B_0xz + (P_1B_1 + P_1F_1)x + C_2 < 0$, i.e., $x < \frac{C_1 - C_2 - P_2B_0z}{P_1B_1 + P_1F_1}$,

$\frac{d\mathrm{F}(y)}{dy}|_{y=0} < 0$, $\frac{d\mathrm{F}(y)}{dy}|_{y=1} > 0$, $y = 0$ is a equilibrium point. For e-commerce enterprises, dishonesty management is a stable strategy in this case.

Asymptotic stability analysis of consumers:

$$\frac{d\mathrm{F}(z)}{dt} = (1-2z)[-P_2C_0 + P_2B_0x - P_2B_0xy) \tag{16}$$

$-P_2C_0 + P_2B_0x - P_2B_0xy = 0$ is a stable demarcation line.

When $-P_2C_0 + P_2B_0x - P_2B_0xy > 0$, i.e., $y < \frac{-P_2C_0 + P_2B_0x}{P_2B_0x}$,

$\frac{d\mathrm{F}(z)}{dz}|_{z=0} > 0$, $\frac{d\mathrm{F}(z)}{dz}|_{z=1} < 0$, $z = 1$ is a equilibrium point. For consumers, the strategy of complaining is a stable strategy.

When $-P_2C_0 + P_2B_0x - P_2B_0xy < 0$, i.e., $y > \frac{-P_2C_0 + P_2B_0x}{P_2B_0x}$,

$\frac{d\mathrm{F}(z)}{dz}|_{z=0} < 0$, $\frac{d\mathrm{F}(z)}{dz}|_{z=1} > 0$, $z = 0$ is a equilibrium point. For consumers, the strategy of not complaining is a stable strategy.

The equilibrium point in the tripartite evolutionary game can be solved by $\begin{cases}\mathrm{F}(x)=0\\ \mathrm{F}(y)=0\\ \mathrm{F}(z)=0\end{cases}$, the following 8 local points of equilibrium can be acquired: $E_1(0, 0, 0)$, $E_2(0, 0, 1)$, $E_3(1, 0, 0)$, $E_4(0, 1, 0)$, $E_5(1, 0, 1)$, $E_6(0, 1, 1)$, $E_7(1, 1, 0)$, $E_8(1, 1, 1)$.

According to the method proposed by Friedman, the Jacobi matrix can be obtained by taking the derivative of the replicator dynamics system. The corresponding asymptotic stability analysis results can be obtained by substituting eight equilibrium points into the matrix.

$$J=\begin{bmatrix}(1-2x)(-C_3+B_3+B_2+P_1F_1-B_2y-P_1F_1y) & x(1-x)(-P_1F_1-B_2) & 0\\ y(1-y)(P_1B_1+P_1F_1+P_0B_2z) & (1-2y)[-C_1+P_2B_0xz+(P_1B_1+P_1F_1)x+C_2] & y(1-y)P_2B_0\\ z(1-z)(P_2B_0-P_2B_0y) & -z(1-z)P_2B_0 & (1-2z)(-C_0P_2+B_0P_2x-C_0y-B_0P_2xy+C_0P_2y)\end{bmatrix} \quad (17)$$

The three Eigenvalues corresponding to each equilibrium point can be obtained by substituting the equilibrium points into the Jacobian matrix. According to Lyapunov indirect method, if all the Eigenvalues of an equilibrium point are negative real numbers, then the equilibrium point is stable. If one Eigenvalue is zero, then the stability of the equilibrium point cannot be judged. If at least one Eigenvalue is not less than zero, then the equilibrium point is unstable. The stability judgment results of the equilibrium points are shown in Tab. 3.

3. Results and discussion

3.1 Results

Situation 1. When $P_1F_1 - C_3 + B_2 + B_3 < 0$, there is a stable point in the replicator dynamics system. That is, the final benefit brought to the government after the successful government supervision is less than the cost of government supervision. At this time, the evolutionary strategy is (loose supervision, dishonesty management, no complaint).

Situation 2. When $C_3 - P_1F_1 - B_3 - B_2 < 0$, $C_2 - C_1 + P_1F_1 + P_1B_1 < 0$, $P_2B_0 - P_2C_0 < 0$, there is a stable point in the replicator dynamics system. That is, the final benefit brought to the government after the successful government supervision is greater than the cost of government supervision; the cost of e-commerce integrity management is greater than the sum of the cost of e-commerce enterprises' dishonesty management, government penalties, and market losses; and the benefit of consumer complaints is less than the cost of complaints. In this case, the evolutionary strategy is (strict supervision, dishonesty management, no complaint).

Situation 3. When $C_3 - P_1F_1 - B_3 - B_2 < 0$, $-C_1 + C_2 + P_1F_1 + P_1B_1 + P_2B_0 < 0$, $-P_2B_0 + P_2C_0 < 0$, there is a stable point in the replicator dynamics system. That is, the final benefit brought to the government after the successful government supervision is greater than the cost of government supervision, the sum of the cost of dishonesty management of e-commerce enterprises, government penalties, market losses, and compensation for consumers is still less than the cost of integrity management; and the benefit of successful consumer complaints is greater than the cost of complaints. In this case, the evolutionary strategy is (strict supervision, dishonesty management, complaint).

Tab. 3: Stability analysis of equilibrium points

Equilibrium point	Eigenvalue	Eigenvalue symbol	Stability
$E_1(0, 0, 0)$	$P_1F_1 - C_3 + B_2 + B_3$, $C_2 - C_1$, $-P_2C_0$	×, –, –	Asymptotically stable point
$E_2(0, 0, 1)$	$P_1F_1 - C_3 + B_2 + B_3$, $C_2 - C_1$, P_2C_0	×, –, +	Unstable point
$E_3(1, 0, 0)$	$C_3 - P_1F_1 - B_2 - B_3$, $C_2 - C_1 + P_1F_1 + P_1B_1$, $P_2B_0 - P_2C_0$	×, ×, ×	Asymptotically stable point
$E_4(0, 1, 0)$	$B_3 - C_3$, $C_1 - C_2$, $-P_2C_0$	×, +, –	Unstable point
$E_5(1, 0, 1)$	$C_3 - P_1F_1 - B_2 - B_3$, $-C_1 + C_2 + P_1F_1 + P_1B_1 + P_2B_0$, $-P_2B_0 + P_2C_0$	×, ×, ×	Asymptotically stable point
$E_6(0, 1, 1)$	$B_3 - C_3$, $C_1 - C_2$, P_2C_0	–, +, +	Unstable point
$E_7(1, 1, 0)$	$C_3 - B_3$, $C_1 - C_2 - P_1F_1 - P_1B_1$, $- P_2C_0$	×, ×, –	Asymptotically stable point
$E_8(1, 1, 1)$	$C_3 - B_3$, $C_1 - C_2 - P_1F_1 - P_1B_1 - P_2B_0$, P_2C_0	+, ×, +	Unstable point

Source: own

Situation 4. When $C_3 - B_3 < 0$, $C_1 - C_2 - P_1F_1 - P_1B_1 < 0$, there is a stable point in the replicator dynamics system. That is, the cost of government supervision is less than the credibility brought by strict supervision of e-commerce enterprises to the government; and the cost of integrity management of e-commerce enterprises is less than the sum of the cost of dishonesty management of e-commerce enterprises, government penalties, and market losses. At this time, the evolutionary strategy is (strict supervision, integrity management, no complaint).

3.2 Discussion

To ascertain the influence of governmental and consumer involvement in the integrity management of e-commerce activities and the effects of changes in relevant parameters, interviews were conducted with representatives of the Hangzhou E-commerce Association in Zhejiang, China. In reference to the current average operating costs of e-commerce enterprises, the existing penalties for unethical e-commerce practices, and consumer feedback mechanisms, specific values were assigned to each parameter for a simulation analysis utilizing Matlab. Compiling interview data and integrating it with the constraints of the model, the following values were determined: the cost incurred by e-commerce enterprises for engaging in dishonesty management was set at 50, whereas maintaining integrity management was estimated at 80. The government's penalty for dishonest management was fixed at 40, and the compensation given to consumers in the event of dishonesty was designated as 20. These specific values, related to the roles of the government and consumers, are detailed in Tab. 4. Moreover, the simulations were set up with an initial timeframe starting at 0 and concluding at 10 for the evolutionary analysis.

With the assumption that the initial strategies of the government, e-commerce enterprises, and consumers are at a moderate level,

Tab. 4: Parameter assignment

Parameter	C_1	C_2	B_1	B_0	C_3	F_1	B_3	B_2	P_1	P_2	C_0
Value	80.0	50.0	40.0	20.0	10.0	40.0	30.0	20.0	0.5	0.5	10.0

Source: own

the initial values of *x*, *y*, and *z* are set to 0.5. The simulation results are shown in Fig. 1 In scenarios where the likelihood of all three entities selecting the initial strategy is minimal (0.1), the corresponding simulation results are exhibited in Fig. 2. Conversely, when the probability of all three choosing the initial strategy is considerably elevated (0.8), the simulation results are displayed in Fig. 3.

The simulation results verify the correctness of the theoretical calculation. No matter what the initial value changes are, the endpoint

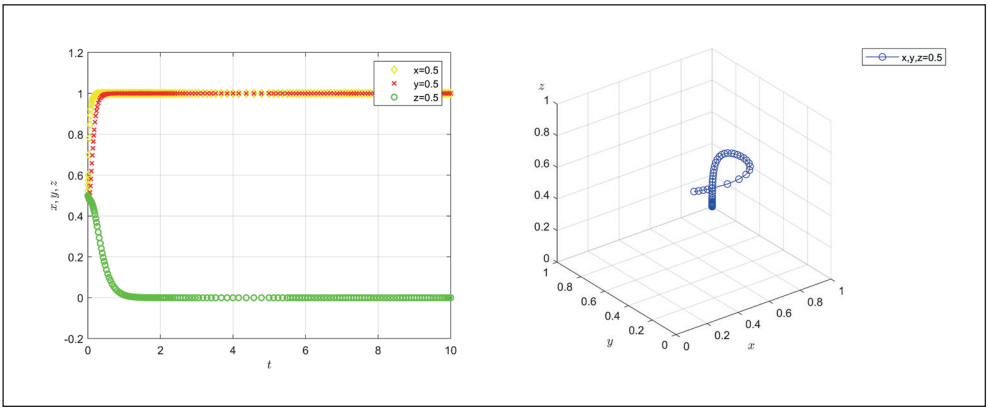

Fig. 1: **Tripartite dynamic evolutionary trend diagram under initial x, y, and z values of 0.5**

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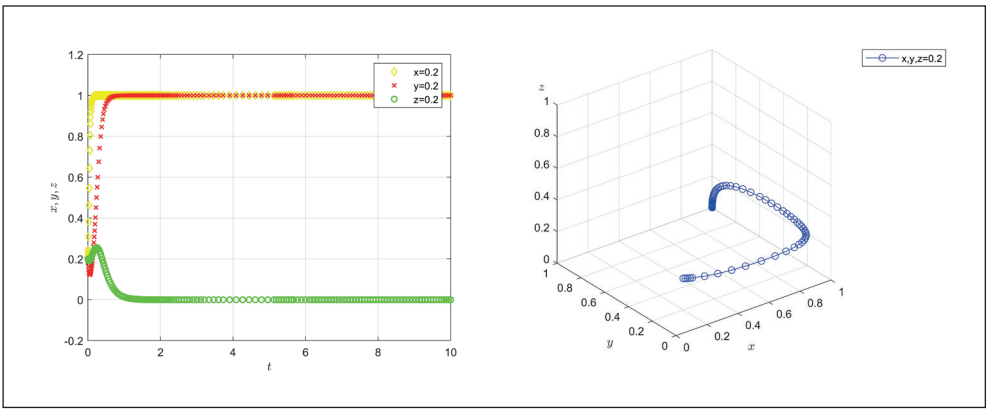

Fig. 2: **Tripartite dynamic evolutionary trend diagram under initial x, y, and z values of 0.2**

Source: own

of the tripartite evolution is (1, 1, 0) when the constraint conditions are assigned. However, the evolutionary path under different initial willingness is not the same despite the same end point of evolution. The evolution path of the government tends to be 1 continuously, with no obvious disturbance in the middle. However, the evolution path of e-commerce enterprises and consumers changes with the initial willingness of the other two parties. Consumers complain when they observe low initial willingness of the government in active

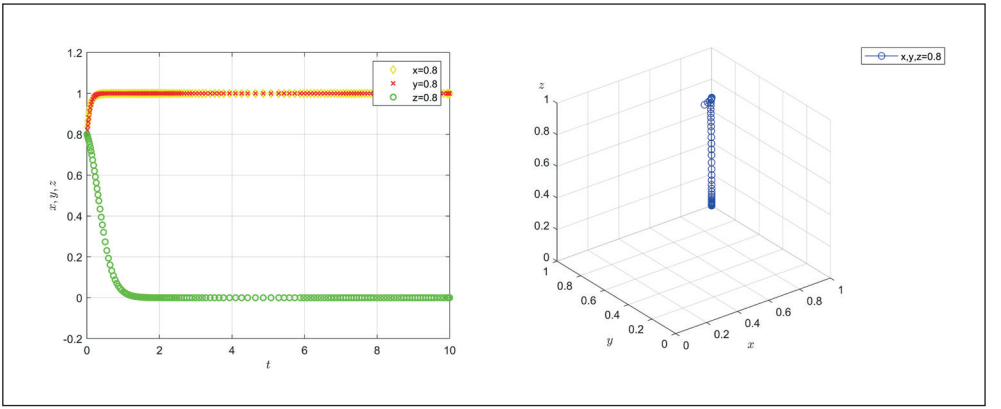

Fig. 3: **Tripartite dynamic evolutionary trend diagram under initial x, y and z values of 0.8**

Source: own

supervision and low willingness of e-commerce enterprises in integrity management. The complaint strategy is not selected by consumers when e-commerce enterprises are inclined to integrity management.

Next, the effects of different parameters on the behaviors of e-commerce enterprises were considered.

(1) Influence of the government penalties imposed on e-commerce enterprises. While the other parameters remained unchanged, the government penalties on e-commerce enterprises were set to 30, 40, and 50 in the simulation, and the influence on enterprise behaviors is displayed in Fig. 4. As the government penalties increase, *y* finally converges to 1, and the convergence speed is accelerated. In this case, e-commerce enterprises finally adopt the integrity management decision.

The simulation results show that the increase of government penalties effectively improves the possibility of integrity management of e-commerce enterprises. That is, in the process of government supervision of e-commerce

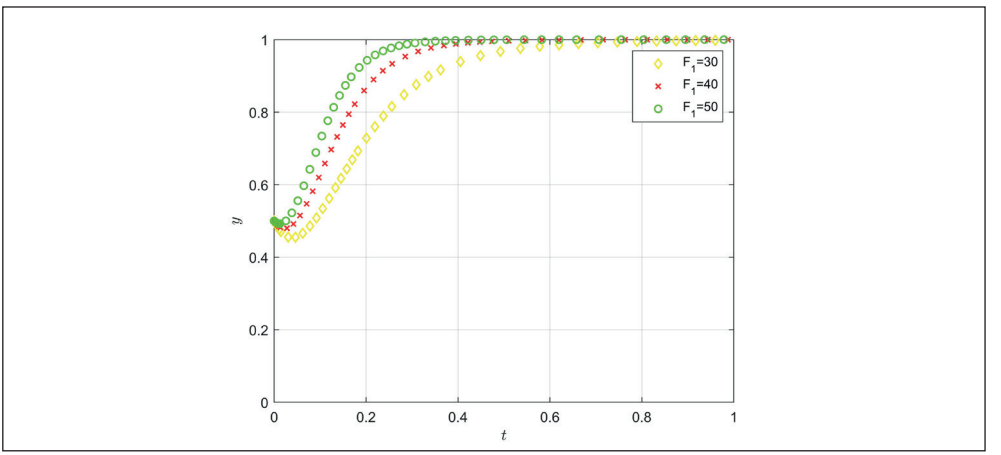

Fig. 4: **Influence of government penalties on enterprise behaviors**

Source: own

enterprises, if the amount of penalties on the dishonesty of e-commerce enterprises increases, then the dishonesty management of enterprises is effectively constrained. Thus, the integrity management behavior of e-commerce enterprises can be promoted by increasing government penalties, which, in turn, can guarantee consumers' rights and interests.

(2) Influence of e-commerce enterprises' dishonesty management costs. While the other parameters remained unchanged, the dishonesty management cost of e-commerce enterprises was set to 45, 50, and 55 in the simulation, and the influence on enterprise behaviors is shown in Fig. 5. As the dishonesty management cost of e-commerce enterprises increases, *y* converges to 1, and the convergence speed is accelerated. In this case, the behavioral decision of e-commerce enterprises evolves to integrity management.

The integrity management cost of e-commerce enterprises exerts a significantly positive effect on the integrity management of e-commerce enterprises. The reason is that as the dishonesty management cost increases, e-commerce enterprises become inclined to integrity management, considering the actual revenue.

(3) Influence of compensation for consumers after dishonesty management. While the other parameters remained unchanged, the simulated compensation for consumers was set to 10, 20, and 30, and the influence on enterprise behaviors is displayed in Fig. 6. As the compensation amount to consumers increases after the dishonesty management of e-commerce enterprises, *y* finally converges to 1, and the convergence speed is gradually accelerated.

The increase in the amount of compensation for consumers can effectively avoid the dishonest behavior of e-commerce enterprises, and the behavior decision of e-commerce enterprises eventually evolve to integrity management. The reason is that with the increase in the compensation amount for consumers due to the dishonest behavior of enterprises, the dishonesty management cost of e-commerce enterprises is indirectly elevated, thereby effectively enhancing their initiative in integrity management.

(4) Influence of dishonesty management on market and reputation losses of e-commerce enterprises. While the other parameters were unchanged, the simulated value was set to 30, 40, and 50, and the influence on enterprise behaviors is displayed in Fig. 7. With the increase in the market and reputation losses brought by dishonesty management to e-commerce enterprises, *y* converges to 1, and the convergence speed is accelerated. In this case, the behavior decision of enterprises finally lean toward integrity management.

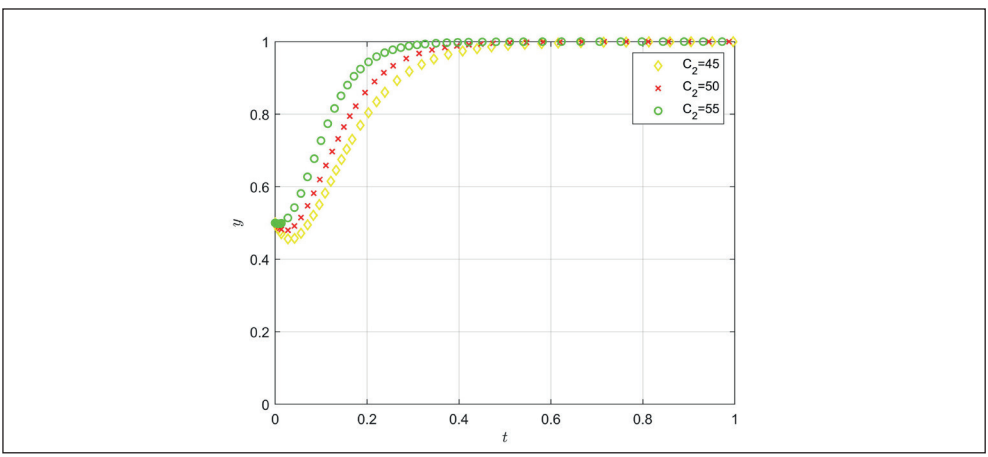

Fig. 5: Influence of dishonesty management cost on enterprise behaviors

Source: own

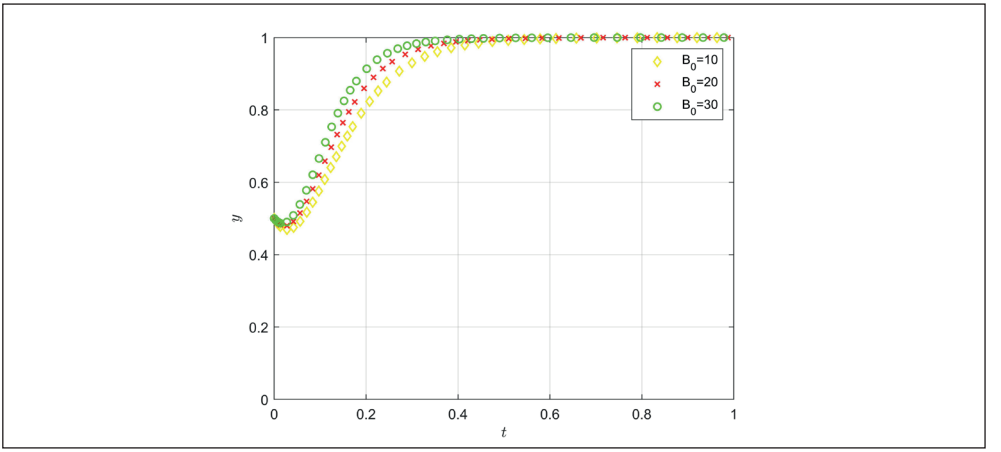

Fig. 6: **Influence of compensation for consumers on enterprise behaviors**

Source: own

The increase in market and reputation losses brought by dishonesty management to e-commerce enterprises effectively improves the enthusiasm of enterprise management. In other words, if the dishonesty management behavior of e-commerce enterprises is discovered by the public, then the reputation of e-commerce enterprises in the market is greatly reduced. Thus, enterprises are more inclined to integrity management to ensure their market reputation. Hence, the integrity management behavior of e-commerce enterprises can be promoted by the increase in market and reputation losses.

(5) Influence of the success probability of government supervision. While the other parameters were unchanged, the simulated value was set to 0.2, 0.5, and 0.8, and the influence on enterprise behaviors is exhibited in Fig. 8. With the increase in the success probability

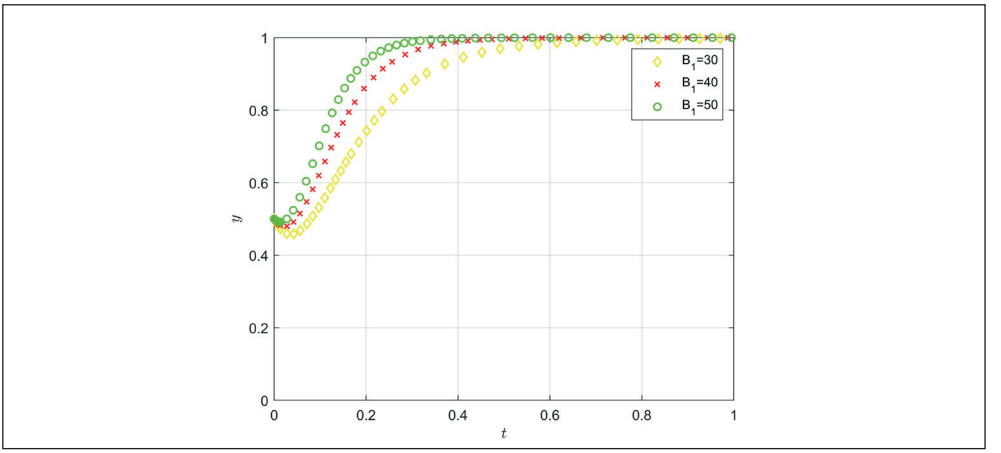

Fig. 7: **Influence of market and reputation loss on enterprise behaviors**

Source: own

of government supervision, y finally converges to 1, and the convergence speed is accelerated. In this case, the behavioral decision of e-commerce enterprises evolves to integrity management. When P_1 is ≤0.2, y finally converges to 0, and the behavioral decision of e-commerce enterprises evolves to dishonesty management.

The increase in the success probability of government supervision has a significantly positive effect on the integrity management of e-commerce enterprises. Without government supervision, the integrity management of e-commerce enterprises becomes challenging, and enterprises may be subjected to the dishonesty problem. When the success probability of government supervision increases, the risk of dishonesty management of e-commerce enterprises declines. Therefore, the government can promote the integrity management of e-commerce

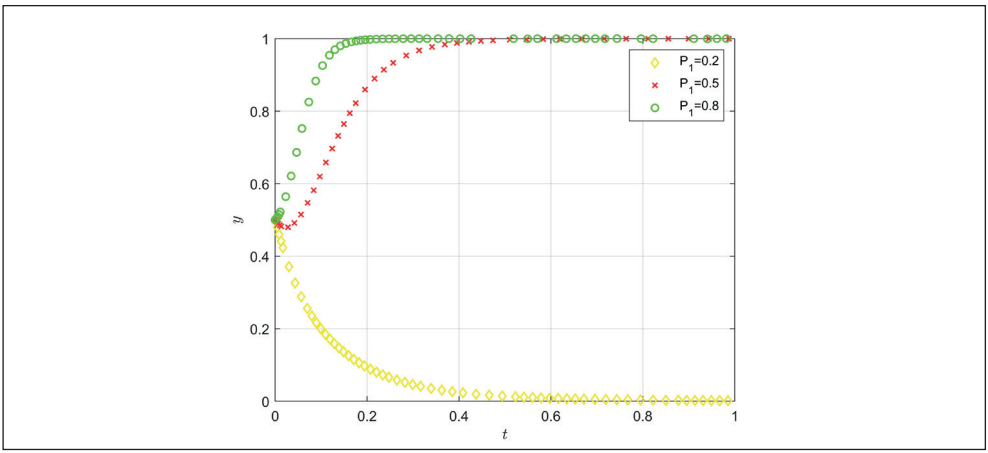

Fig. 8: **Influence of success probability of government supervision on enterprise behaviors**

Source: own

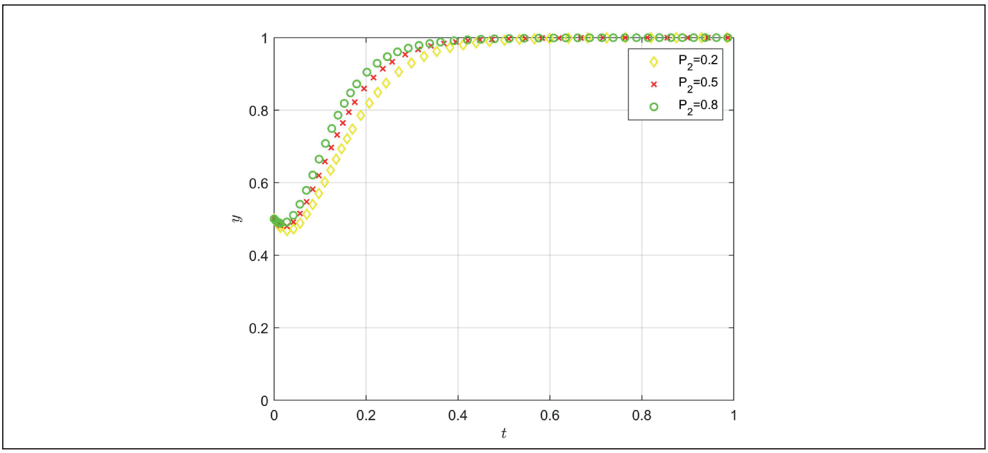

Fig. 9: **Influence of success probability of consumer complaints on enterprise behaviors**

Source: own

enterprises by establishing a long-term supervisory mechanism.

(6) Influence of the probability for consumers to find the dishonesty management of enterprises and complain successfully. While the other parameters remained unchanged, the simulated value was set to 0.2, 0.5, and 0.8, and the influence on enterprise behaviors is displayed in Fig. 9. As the probability for consumers to find the dishonesty management of enterprises and complain successfully increases, *y* finally converges to 1, and the convergence speed is accelerated. In this case, the behavioral decision of e-commerce enterprises leans toward integrity management.

The increase in the probability of successful consumer supervision can promote e-commerce enterprises to choose the integrity management strategy. The reason is that as the success probability of consumer complaints increases, the dishonest behaviors of enterprises can be found. When the compensation and market loss to be undertaken by e-commerce enterprises after their dishonest behavior are discovered, enterprises tend to adapt integrity management.

Conclusions

This study analyzed the dishonest practices of e-commerce enterprises from the perspective of daily activity theory. A tripartite evolutionary game model encapsulates the government, e-commerce enterprises, and consumers was established. The study findings are as follows.

First, from the perspective of motivation, the main driving force for e-commerce enterprises to engage in dishonest practices comes from the additional benefits they may bring. If the additional benefits of e-commerce enterprises are lower than the compensation and reputation losses of consumers, as well as the fines imposed by strict government supervision, then the motivation for e-commerce enterprises to engage in dishonest practices is insufficient, and the strategy evolution of e-commerce enterprises is stable in integrity management.

Second, from the perspective of opportunities, an increase in the effectiveness of government regulation and consumer complaints raises the probability of e-commerce enterprises being discovered for dishonest practices. The situation can effectively reduce the probability of e-commerce enterprises engaging in dishonest management.

Third, from the perspective of control methods, the government's punishment for dishonest management of e-commerce enterprises and the effectiveness of government regulation can effectively reduce the motivation for dishonest management of e-commerce enterprises. Meanwhile, consumer participation in co-governance regulation through complaints can also have a positive effect.

On the basis of the aforementioned conclusions, the following three implications are proposed.

First, a feasible reward and punishment mechanism should be established. Government incentives for e-commerce enterprises operating with integrity should be created to enhance their public recognition and visibility. At the same time, the punishment for dishonest practices should be increased, the standards for identifying serious dishonesty and illegal lists of e-commerce enterprises should be improved, the integrity blacklist system and market exit mechanism of e-commerce should be standardized, and dishonest enterprises should be guaranteed to receive corresponding punishment. The construction of a consumer co-governance regulatory system should be continuously promoted. The mechanism for safeguarding rights should be improved, and the protection of consumer rights should be guaranteed. The government should also improve relevant legislation, open dedicated channels for consumer complaints, promptly and efficiently handle consumer complaints, and safeguard consumer rights.

Second, the awareness of integrity among e-commerce enterprises should be enhanced. Integrity is crucial for business practices, and e-commerce enterprises should strengthen the construction of an integrity culture to gain consumers' trust and recognition and establish an integrity image for consumers. The government should guide regional e-commerce industry associations to build and improve the integrity system of the e-commerce industry. Integrity management evaluations of e-commerce enterprises should be regularly conducted while promptly disclosing them to the public. Moreover, market reputation should be emphasized, and a virtuous cycle of competition in the e-commerce market should be initiated.

Third, consumers should actively participate in the integrity evaluation of e-commerce enterprises. Actively participating in co-governance supervision not can only promote e-commerce

enterprises to operate with integrity but also reduce the risk of complaints faced by other consumers in the future. Consumer feedback on the dishonest practices of e-commerce enterprises can reduce information asymmetry, transmit effective information to relevant government regulatory agencies, and curb the dishonest practices of e-commerce enterprises to a certain extent.

This study theoretically constructs a model for the integrity management of e-commerce enterprises and simulates the strategic choices of the government, e-commerce enterprises, and consumers. However, given the constraints of research conditions, numerical simulation lacks practical data support, and further exploration is needed to empirically analyze theoretical models through actual data. The integrity management of e-commerce enterprises involves multiple aspects. This study only analyzes the influence of government and consumers on the decision-making of e-commerce enterprises. In reality, there are other entities and factors that can also affect the integrity management of e-commerce enterprises. In future research, the focus would be on expanding the investigation of strategic decisions involving additional entities to enrich the evolutionary game scenarios.

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Factors influencing career sustainability in Saudi Arabian banks: A PLS-SEM analysis

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Abstract: *This research delves into the correlation between organizational career growth and its impact on career sustainability among employees in the Saudi Arabian banking sector. It also explores the mediating influence of task performance and organizational citizenship behavior. Utilizing self-reported online questionnaires, data was collected from employees in Jeddah and Riyadh, Saudi Arabia, working in both private and public banks. Approximately 255 surveys were gathered, and thorough scrutiny of the data was conducted to identify any instances of common bias, duplication, or missing values. Following this data cleaning process, a sample size of 200 was retained for subsequent analysis. The survey, conducted over a month from December 2022 to January 2023, targeted four key factors: organizational career growth (OCG), organizational citizenship behavior, task performance, and career sustainability. The study utilized partial least squares structural equation modeling (PLS-SEM) and path analysis, a combination that allows observed variables to represent latent variables while elucidating causal relationships between them. The findings showed that organizational career growth has a positive and significant influence on organizational citizenship behavior, task performance, and career sustainability. The SRMR value of 0.078 indicates a good fit between the observed data and the model; while the normed fit index (NFI) score of 0.957 shows that the model fits the data well. In addition, the study utilized the blindfolding technique to evaluate the model's predictive validity. The results show that organizational career growth exerts a moderate effect on both task performance (Q2 = 0.218, Q2 = medium effect) and career sustainability (Q2 = 0.281, Q2 = medium effect) and has a limited impact on organizational citizenship behavior (Q2 = 0.136, Q2 = small effect). Expanded career opportunities within the organization led to better task performance and organizational citizenship behavior, indirectly boosting employees' career sustainability in banking sector. Detailed managerial insights are also provided.*

Keywords: *Organizational career growth, career sustainability, organizational citizenship behavior, task performance, banking sector.*

JEL codes: *C38, C52, J24, L29, M10, M54, O15.*

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Introduction

Organizational career growth is vital for ensuring career sustainability, particularly in an environment like Saudi Arabia, where profoundly influences individual career paths. It asserts that career growth opportunities,

encompassing promotions, compensation, professional development, and training, positively impact career sustainability (Bozionelos et al., 2020). Investments in employee career growth demonstrate organizational commitment, foster a positive culture, and enhance task performance and career sustainability. Alshaabani et al. (2021) research suggests that perceived organizational support for career growth correlates with higher organizational citizenship behavior and commitment. Prioritizing employee growth contributes to improved retention, reduced turnover, and increased motivation, enhancing career sustainability in Saudi Arabia. The major objective is to investigate the influence of organizational career growth on employees' career sustainability, measured through organizational citizenship behavior and task performance.

The research emphasis on employees in Saudi Arabian banks raises two key investigations: the influence of organizational career growth on career sustainability and the mediating functions of organizational citizenship behavior (OCB) and task performance in this dynamic (Weng et al., 2010). While existing studies have explored factors such as organizational commitment, work engagement, leadership, individual career management, employee voice behavior, career development, sustainable careers, and turnover intentions (Canaj et al., 2021; Son & Kim, 2021; Wang et al., 2014; Weng & McElroy, 2012; Wickramaratne, 2020), they have not thoroughly investigated the relationship between organizational career growth and career sustainability, particularly among Saudi Arabian bank employees. Tordera et al. (2020) findings highlight the imperative of understanding how human and organizational factors affect long-term career sustainability, especially in relation to well-being and employee/task performance. Consequently, there is a need for empirical investigations into how organizational career growth shapes career sustainability within the distinctive cultural and organizational milieu of Saudi Arabian banks (Müller et al., 2022). Moreover, the proposed research aims to investigate the mediating role of organizational citizenship behavior (OCB) and task performance in this relationship. While previous research has explored the influence of OCB and task performance on career outcomes (Koopmans et al., 2014; Podsakoff et al., 2009), there is a dearth of studies focusing on their specific mediating role within the banking sector in Saudi Arabia (Al Balushi et al., 2022).

Therefore, the purpose of our research is to address the research gap by empirically investigating the mechanisms among organizational career growth factors (professional ability development, promotion speed, and remuneration growth) and their influence on career sustainability, aiming to create environments within Saudi Arabian banks that support sustainable careers, benefiting both employees and organizations. Additionally, by aligning our study with the banking sector, we enhance its theoretical contributions to the existing body of literature and research methodology.

1. Theoretical background

1.1 Theoretical framework and hypothesis development

Various theoretical frameworks enrich our understanding of organizational career growth. Social cognitive career theory, proposed by Lent et al. (1994), emphasizes self-efficacy, outcome expectations, and personal goals. Career construction theory, introduced by Savickas (2013), delves into subjective work experiences and meanings. Conservation of resources (COR) theory by Hobfoll (1989) explains how career growth provides increased resources, fostering positive work outcomes. Self-determination theory, advocated by Deci and Ryan (2000), gives emphasis to individual psychological needs for career growth. Integrating these perspectives provides a comprehensive understanding of organizational career growth's impact on employees. Savickas (2013) extends the conversation, offering frameworks within career construction theory for understanding career sustainability and highlighting self-reflection, adaptability, and proactive management as crucial elements. Continuous learning, growth, and resource acquisition, aligned with Hobfoll's (1989) COR theory, play pivotal roles in achieving career sustainability.

Organizational citizenship behaviors (OCB) go beyond job requirements, benefiting organizations. Social exchange theory (Blau, 1964) underscores reciprocity in employee-organization relationships. Social learning theory (Bandura, 1977) highlights behavior learning through observation. OCB positively influences job satisfaction, commitment, and overall effectiveness (Organ & Ryan, 1995). Understanding these theories fosters a culture

encouraging such behavior. Task performance, integral to job responsibilities, is influenced by theoretical frameworks like goal-setting theory (Locke & Latham, 2002), social cognitive theory (Bandura, 1986), and self-determination theory (Deci & Ryan, 1985). Aligning tasks with individual goals enhances employee productivity, job satisfaction, and organizational effectiveness, which are vital for organizational success. Based on the theoretical framework mentioned above, we formulated the following research objectives:

- *Explore the influence of organizational career growth on organizational citizenship behavior, task performance, and career sustainability.*
- *Examine how the relationship between organizational career growth and career sustainability is mediated by the role of organizational citizenship behavior and task performance.*

1.2 Banking sector in Saudi Arabia

Career sustainability in Saudi Arabian banks is significantly influenced by organizational career growth – a pivotal factor. The surge in the number of banks to 28 in 2020, with total assets reaching 775.29 billion USD, signals substantial career prospects as shown by Saudi Arabian Monetary Authority (2020). The recent focus on organizational career growth emphasizes its pivotal role in fostering career sustainability. This involves individuals progressing within an organization, enhancing skills, knowledge, and experience – essential for thriving in the dynamic Saudi Arabian banking landscape. Organizational career growth positively influences organizational citizenship behavior (voluntary actions benefiting the organization) and task performance (meeting or surpassing performance expectations; Bozionelos et al., 2020; Lo Presti et al., 2019).

Organizational citizenship behavior (OCB), demonstrated through actions like assisting colleagues and exceeding job expectations, is vital for career sustainability. High OCB levels enhance perceived commitment, potentially leading to increased career opportunities and job security, as proclaimed by Bolino et al. (2013). Task performance, which refers to an employee's ability to perform their job duties effectively (Williams & Anderson, 1991), is vital in Saudi Arabian banks, encompassing activities such as meeting sales targets, providing exceptional customer service, and ensuring regulatory compliance. Organizational career growth significantly influences OCB and task performance, positively contributing to long-term career sustainability (Bozionelos et al., 2020; Lo Presti et al., 2019).

In the Saudi Arabian banking sector, challenges affecting career growth and sustainability go beyond gender disparities (Alshehri & McLauglin, 2021). These encompass fostering employee engagement, understanding the interplay between HRM practices, employee job satisfaction, and sustainable competitive advantages, as suggested by Tawfig and Kamarudin (2022), as well as the impact of HRM practices on employee engagement and organizational commitment (Alshehri et al., 2017; Cherif, 2020). The Saudization policy significantly influences recruitment and retention, with training and revised working hours being crucial (Edgar et al., 2016). Retention challenges and high turnover rates further hinder career stability, compounded by intricate regulatory environments. Economic uncertainties and evolving customer expectations contribute to the complex workforce landscape. Tackling these issues requires a strategic emphasis on continuous learning, diversity promotion, and cultivating inclusive workplace cultures to ensure professionals' long-term career growth and sustainability in the Saudi Arabian banking sector. These studies accentuate the need for robust organizational cultures, sustainable competitive advantages, and effective HRM strategies to address challenges and trends in the Saudi Arabian banking industry.

1.3 Review literature

Organizational career growth and its impact on career sustainability

Research has consistently demonstrated a positive relationship between organizational career growth and various career-related outcomes such as organizational citizenship behavior, task performance, and career sustainability. For instance, Biswakarma (2016) found that dimensions of organizational career growth are negatively related to employees' turnover intentions. Recent studies have also highlighted the role of career management practices (CMPs) and lifelong learning in promoting organizational career growth and career sustainability. Wickramasinghe and Premachandra (2021) found that CMPs driven by both

organizations and employees of medium-sized enterprises in Sri Lanka have positive effects on organizational career growth, while Liu et al. (2022) found that lifelong learning positively influences career sustainability. Furthermore, Tordera et al. (2020) discovered that various HR practices could contribute to sustaining careers. Organizational commitment, which is closely linked to career sustainability, has been shown to have a positive relationship with career growth (Weng et al., 2010). Thus, promoting organizational career growth can help foster career sustainability and retain talented employees in the long run.

Bai (2018) suggested that career advancement has a clear impact on an individual's sense of organizational identity, leading to a better fit between the individual's values and those of the organization. It is essential for organizations to prioritize organizational career growth, as it is a vital factor in ensuring long-term career success. Companies should invest in career management programs, continuous learning opportunities, diverse human resources practices, and initiatives to promote organizational identification to encourage organizational career growth and retain skilled employees.

H1a: Organizational career growth has an impact on career sustainability.

Organizational career growth and its impact on organizational citizenship behavior

Several studies have demonstrated that employees who perceive opportunities for career growth within an organization are more likely to engage in organizational citizenship behavior (Bagdadli & Gianecchini, 2019). For example, Bagdadli and Gianecchini (2019) revealed that career growth opportunities were positively related to organizational citizenship behavior in a sample of Turkish employees. Similarly, a study by Bolino et al. (2013) found that perceived organizational support for career development was positively related to organizational citizenship behavior in a sample of US employees.

Recent research has also shown that the relationship between career growth and organizational citizenship behavior may be mediated by psychological empowerment (Huang et al., 2019). Huang et al. (2019) found that career growth opportunities were positively related to psychological empowerment, which in turn was positively related to organizational citizenship behavior in a sample of Chinese employees. In addition, organizational career growth may also influence other dimensions of employee behavior, such as job satisfaction and turnover intentions (Japor, 2021).

Overall, the evidence suggests that providing opportunities for career growth and development can lead to positive outcomes for both employees and organizations. Managers should thus prioritize career growth as a means of fostering employee engagement and citizenship behaviors.

H1b: Organizational career growth has an impact on organizational citizenship behavior.

Organizational career growth and its impact on task performance

Previous literature on the relationship between organizational career growth and task performance has yielded mixed results. A research study conducted by Vianello et al. (2022) suggests that career calling can enhance job performance, but this effect may be weakened in high-demand jobs. In contrast, Haynie et al. (2020) found that career adaptability and job engagement could enhance task performance. Furthermore, Kalia and Bhardwaj (2019) found that task performance may increase with age, but contextual performance may peak at middle age, and both may be influenced by the type and size of organization.

According to Bal et al. (2015), there is a positive link between employees customizing their careers, job attitudes, and subsequent objective career success. This implies that organizational career growth can positively affect task performance. However, further research is required to investigate potential moderating factors influencing this relationship. There are several variables that influence the relationship between organizational career growth and task performance, making it a complicated and diverse effect. According to Schuler (1977), individual variables play a mitigating role in this impact, such as job participation and growth needs. In the Develi et al. (2022) investigation, personal growth initiative was found to operate as a mediator between task performance and job satisfaction. It also demonstrates that organizational career growth has a favorable impact on work engagement and that organizational identification acts as a mediating factor (Bai & Liu, 2018). Wickramasinghe and Premachandra (2021) conclude

by highlighting the role that career management strategies have in improving organizational career growth and how that can affect task performance. The extensive research accentuates how individual differences, personal development endeavors, job involvement, and strategies for career management all play pivotal roles in shaping the association between organizational career advancement and task effectiveness.

H1c: Organizational career growth has an impact on task performance.

Organizational career growth and its impact on organization citizenship behavior and career sustainability

Organizational career growth is vital for employees and organizations alike, addressing the needs for advancement and skill development. An important outcome is its positive influence on organizational citizenship behavior (OCB), referring to voluntary actions beyond job requirements. Research conducted by Liu et al. (2022) indicates that employees perceiving opportunities for career growth are more inclined to engage in OCB, contributing to a supportive workplace culture and organizational success. In addition, organizational career growth is vital for career sustainability, equipping employees with skills to navigate job and industry changes. Access to training and development enhances employees' career management, ensuring relevance and adaptability (Orduna, 2022).

Son and Kim (2021) revealed that the association between organizational career growth and career commitment is mediated by work engagement. Similarly, Jiang et al. (2017) observed that organizational citizenship behavior mediates the relationship between transformational leadership and sustainable employee performance. As a result, these studies imply that organizational career growth may raise the possibility of greater organizational citizenship behavior, which in turn could have an impact on career sustainability.

Hence, organizational career growth is essential for both employees and organizations, as it has a positive impact on organizational citizenship behavior and career sustainability. By providing employees with opportunities for development and advancement, organizations can create a more engaged workforce and support the long-term career success of their employees.

H2: Organizational career growth has an impact on career sustainability mediated by organizational citizenship behavior.

Organizational career growth and task performance and career sustainability

The relationship between organizational career growth, task performance, and career sustainability has yielded mixed results, as indicated by various studies. Lee and Lee (2018) discovered that job satisfaction and organizational commitment are crucial individual factors that impact job performance through career development. This suggests that organizational career growth may enhance task performance and contribute to career sustainability.

According to Ingusci et al. (2021) task performance mediates the relationship between organizational career growth and career sustainability. In other words, employees who have access to career growth opportunities tend to perform better at their job, which in turn leads to career sustainability. These findings are supported by earlier research conducted by Cabrera et al. (2024), which suggests that career growth opportunities enhance employees' job performance. Organizational career growth also has a positive impact on employees' job satisfaction, which further affects their career sustainability.

A study by Spagnoli (2017) found that career growth opportunities were positively related to job satisfaction, which subsequently increased career sustainability. Recent research suggests that organizational career growth has a positive impact on career sustainability, mediated by task performance. By providing employees with opportunities for development and advancement, organizations can enhance task performance and job satisfaction, which in turn leads to career sustainability.

H3: Organizational career growth has an impact on career sustainability mediated by task performance.

Organizational citizenship behavior and career sustainability

Organizational citizenship behavior refers to the voluntary actions of employees that go beyond their formal job requirements to benefit the organization. Recent research suggests that organizational citizenship behavior has a positive impact on career sustainability. For instance, studies shown by Jiang et al.

(2017) found that organizational citizenship behavior mediates the relationship between transformational leadership and employee sustainable performance. Similarly, a study by Freire and Pieta (2021) found that organizational citizenship behavior positively affects career sustainability through its impact on job satisfaction. Thus, organizational citizenship behavior appears to be a key factor in sustaining a fulfilling and rewarding career over time.

Chandra and Mathur (2021) discovered that respondents' work attitudes were positively influenced by their involvement, satisfaction, and commitment to their work roles. Lo Presti et al. (2019) revealed that factors such as relational and balanced psychological contracts, a growth-oriented career mindset, and boundaryless thinking have a positive impact on organizational citizenship behavior, which, in turn, is closely related to career sustainability. Therefore, companies must be attentive to their employees' psychological contracts and their overall career satisfaction since it affects their willingness to engage in organizational citizenship behavior. The study findings, combined with prior research, imply that organizational citizenship behavior can have a beneficial effect on sustaining one's career.

H4: Organizational citizenship behavior has an impact on career sustainability.

Task performance and career sustainability

Task performance is the degree to which an employee effectively completes their job responsibilities. Recent research has suggested that task performance has a positive impact on career sustainability. A study conducted by Ingusci et al. (2021) found that task performance mediates the relationship between organizational career growth and career sustainability. In addition, job performance is positively related to career sustainability in the hospitality industry, as proclaimed by Cesário et al. (2022).

Bozionelos et al. (2020) found that an employer-sponsored training program had a positive impact on employees' job performance and employability. This was mainly attributed to the program's ability to increase employees' receptiveness to new experiences and provide them with supportive supervision, resulting in greater career stability. Consequently, it is reasonable to assume that a significant association exists between an individual's task performance and the sustainability of their career. Therefore, we can conclude that task performance is strongly linked to career sustainability.

Udayar et al. (2021) discovered that positive work events could contribute to career sustainability, indicating that task performance may also enhance career sustainability. Meanwhile, a recent study by Adekiya (2024) suggested that task performance has a significant positive effect on job satisfaction. Given the relevance of job satisfaction to career sustainability, this highlights the importance of task performance.

H5: Task performance has an impact on career sustainability.

2. Research methodology

Data was collected through self-reported questionnaires distributed online, targeting employees working in private and public banks in Jeddah and Riyadh, Saudi Arabia. Approximately 255 surveys were gathered, and thorough scrutiny of the data was conducted to identify any instances of common bias, duplication, or missing values. Following this data cleaning process, a sample size of 200 was retained for subsequent analysis. The data collection period spanned one month, from the end of December 2022 to the start of January 2023. The questionnaire was translated both in English and Arabic.

The surveys created for this study aimed to gather information about four specific factors: organizational career growth, organizational citizenship behavior, task performance, and career sustainability. Respondents were asked to rate each item using a five-point Likert scale, where 1 represented "strongly disagree" and 5 represented "strongly agree."

The initial phase of the study evaluated organizational career growth using a 15-item scale developed by Weng et al. (2010). Organizational career growth was broken down into four main subcategories: career goal progress, which gauged progress towards career objectives; professional ability development, which measured growth in professional skills and expertise; promotion speed, which assessed the rate of promotion; and remuneration growth, which determined salary increases over a minimum three-month period with the current employer. Remuneration growth was measured using a 3-item scale, while the first three dimensions were measured using 4-item scales. Examples of items in each subcategory include "My current job is helping me achieve my career

goals," "My current job motivates me to continually develop job-related skills," "I am being promoted quickly in my current organization," and "My salary is increasing rapidly in my current organization." These items were found to have high reliability (∞ 0.904) and validity (with an average variance extracted score of above 0.50).

Organizational citizenship behavior was evaluated using a 6-item scale adapted from the study conducted by Spector et al. (2010) that aimed to measure the frequency of citizenship behaviors in the workplace. The scale assessed how often respondents or others engaged in each behavior. Participants rated their level of agreement with six items on a scale from 1 (strongly disagree) to 5 (strongly agree). These items were deemed reliable (∞ 0.815) and valid (with an average variance extracted score of above 0.50). The task performance (TP) scale was made up of five items that were adapted from the research of Koopmans et al. (2014). The items assessed various aspects of task performance, such as whether the work was completed on time or whether the quality met expectations. Respondents rated their level of agreement with each item on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The TP scale demonstrated good reliability (∞ 0.823) and validity (with an average variance extracted score of above 0.50).

To assess career sustainability, we used the scale developed by Chin et al. (2021). The scale consisted of 11 out of 12 items that were related to various aspects of one's career. The items included statements such as "My profession allows me to continuously learn new things," "My career enables me to critically evaluate information from different sources," and "My career makes me happy because I can utilize my skills effectively." Participants were asked to rate their level of agreement with each item using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The career sustainability scale demonstrated good reliability (∞ 0.926) and validity (with an average variance extracted score of above 0.50).

3. Results

3.1 Result analysis

The study employed partial least squares structural equation modeling (PLS-SEM) in conjunction with path analysis to evaluate their hypotheses, following the suggestion of Rasoolimanesh et al. (2021). PLS-SEM and path analysis enabled a comprehensive analysis of the relationships between the variables under investigation.

The study implemented several techniques to minimize common method bias and social desirability bias. The researchers used statistical and procedural remedies to minimize common method variance, such as assuring participants of their anonymity, randomizing the measurement of variables, and employing Harman's single-factor test to detect any unidimensionality. The results of Harman's single-factor test showed that the variance accounted for by a single factor was less than 50%, indicating the absence of common method variance. Additionally, outliers were identified and removed from the dataset based on a significance level of $p < 0.001$, as suggested by Tabachnick and Fidell (2019). The mean, standard deviation, and bivariate Pearson correlation of the variables are shown in Tab. 1.

The preeminent portion of responses, constituting 96.7%, identifies as "Saudi," with a minority, 3.3%, falling into the "non-Saudi" category. In terms of banking affiliation, the predominant majority of responses, at 81.3%, align with "public banks," while the remaining 18.7% are linked to "private banks." Gender-wise, 55.1% of respondents are male and 44.9% are female. Tab. 1 illustrates the distribution of responses across various age groups, revealing that a significant proportion falls within the less than 25 years and 25–30 years categories. Concerning educational qualifications, a substantial 68.7% of respondents hold a Master's degree, followed by 18.7% with a Bachelor's degree, and 12.6% with a Diploma. Marital status indicates that 70.1% of respondents are married, with the remaining 29.9% being single.

Validity and reliability of the reflective constructs

The accuracy and dependability of the reflective constructs – namely organizational career growth (OCG), organizational citizenship behavior (OCB), task performance (TP), and career sustainability (CS) – were confirmed. In this study, the researcher evaluated the reliability and validity of reflective constructs using the formula proposed by Dijkstra and Henseler (2015). To ensure the quality of the items, Dijkstra et al. (2015) recommend a factor loading of at least 0.60, composite reliability

Tab. 1: Descriptive statistics and bivariate Pearson correlation

	Descriptive		Bivariate Pearson correlations			
	Mean	SD	1	2	3	4
Organization	2.495	0.755				
Nationality	1.032	0.178				
Working experience	3.509	1.702				
AGE	3.649	1.763				
Qualification	3.023	0.623				
Marital status	1.747	0.486				
Organizational career growth	4.044	0.647	1			
Organizational citizen behavior	4.122	0.441	0.077*	1		
Task performance	4.059	0.472	0.131*	0.467*	1	
Career sustainability	4.100	0.536	0.131*	0.419*	0.540*	1

Note: ** correlation is significant at the 0.01 level (2-tailed).

Source: own (using SPSS software)

Tab. 2: Reliability, AVE and VIF values of reflective model – Part 1

Constructs	Items	Type	Loadings	a	Rho-A	CR	AVE	VIF
Organizational career growth scale	CGP1	Reflective	0.607	0.904	0.911	0.919	0.533	1,296
	CGP2		0.732					2,014
	CGP3		0.678					2,288
	CGP4		0.698					2,169
	PAD1		0.641					1,993
	PAD2		0.6487					2,622
	PAD3		0.711					2,467
	PAD4		0.745					2,843
	PS1		0.654					2,361
	PS2		0.683					1,531
	PS3		0.691					1,956
	PS4		0.702					2,070
	RG1		0.656					2,303
	RG2		0.756					2,640
	RG3		0.724					2,583

Tab. 2: Reliability, AVE and VIF values of reflective model – Part 2

Constructs	Items	Type	Loadings	a	Rho-A	CR	AVE	VIF
Organizational citizenship behavior	OCB2	Reflective	0.779	0.815	0.817	0.867	0.523	2,078
	OCB3		0.769					2,022
	OCB5		0.745					1,574
	OCB6		0.701					1,512
	OCB7		0.729					1,579
	OCB9		0.609					1,254
Task performance	TP1	Reflective	0.733	0.823	0.826	0.876	0.588	1,505
	TP2		0.789					1,816
	TP3		0.767					1,691
	TP4		0.843					2,133
	TP5		0.692					1,487
Career sustainability	CSF1	Reflective	0.735	0.926	0.928	0.937	0.575	2,003
	CSF2		0.755					2,253
	CSF3		0.735					2,058
	CSI1		0.774					2,704
	CSI2		0.767					2,581
	CSI3		0.775					2,302
	CSR2		0.752					2,523
	CSR3		0.769					2,802
	CSRE1		0.784					2,218
	CSRE2		0.777					2,282
	CSRE3		0.716					2,180

Note: a – Cronbach alpha; CR – composite reliability; AVE – average variance extracted; VIF – variance inflation factor; CGP – career goal progress; PAD – professional ability development; PS – speed; RG – remuneration growth; OCB – organizational citizen behavior; TP – task perfromance; CSF – career sustainability fexible; CSI – career sustainability information; CSR – career sustainability resourceful; CSRE – career sustainability renewable.

Source: own (developed from SMART PLS-SEM)

of at least 0.70, and an average variance extracted of at least 0.50. The researcher followed Hair et al. (2020) recommendations by excluding four items of organizational citizenship behavior and one item of career sustainability due to low factor loadings, which were less than 0.60.

According to Dijkstra and Henseler (2015) and Hair et al. (2020), all reflective constructs demonstrated acceptable loadings ranging from 0.607 to 0.843. The composite reliability (CR) values for organizational career growth (0.919), organizational citizenship behavior (0.867), task performance (0.876), and career sustainability (0.937) all met satisfactory criteria. The average variance extracted (AVE) values for convergent validity were also deemed acceptable, ranging from 0.523 to 0.588. Additionally, there was no multicollinearity present, as indicated by the VIF values for all items being less than 1.8. Tab. 2 shows the composite

Tab. 3: Discriminant validity using Fornell-Larcker criterion and HTMT criterion

	Fornell-Larcker criterion				Heterotrait-monotrait (HTMT) criterion			
	CS	OCB	OCG	TP	CS	OCB	OCG	TP
CS	**0.758**							
OCB	0.430	**0.723**			0.488			
OCG	0.643	0.303	**0.730**		0.683	0.357		
TP	0.545	0.472	0.494	**0.767**	0.618	0.573	0.561	

Note: The bold numbers in diagonal in Fornell-Larcker section are square root of AVE of each construct, and other numbers are correlation between constructs; OCG – organizational career growth; OCB – organizatinal citizen behavior; TP – task performance; CS – career sustainability.

Source: own (developed from SMART PLS-SEM)

reliability, AVE values for convergent validity, and VIF values.

To evaluate discriminant validity, the researcher employed both the heterotrait-monotrait (HTMT) approach and the Fornell-Larcker criterion. As shown in Tab. 3, both techniques indicated adequate discriminant validity. According to Fornell and Larcker (1981), the square root AVE value of each construct should be greater than its correlation with other constructs. Additionally, the approved HTMT values for the HTMT approach can be less than 0.85, as recommended by Henseler et al. (2015).

This study utilized the blindfolding technique to evaluate the model's predictive validity. The SRMR, a commonly employed model fit index, is the first value reported in Tab. 4 of the model evaluation. In this investigation, the SRMR value was 0.078, which indicates that the observed data and the model fit well.

The sum of squares of observations (SSO) and the sum of squares of errors (SSE) are the third and fourth measures provided in Tab. 4. These metrics evaluate how well the model describes the observed data. The SSO values for OCB, TP, and CS in this investigation were (1,070.00), (1,206.00), and (2,354.00), and the SSE values are (924.20), (942.60), and (1,692.48). These findings indicate that the model adequately explains a substantial part of the variance in the outcome variables.

The Q^2 and Q2 effect values are presented in the final column of Tab. 4. The Q2 measure evaluates the model's predictive validity, whereas the Q2 effect quantifies the effect size of each endogenous construct on its corresponding exogenous construct. The endogenous variables in Tab. 3 are OCB (Q2 = 0.136, Q2 effect = small); TP (Q2 = 0.218, Q2 effect = medium); and CS (Q2 = 0.281, Q2 effect = medium) respectively.

The results distinctly indicate that the progression of organizational career growth positively influences the endogenous variables, as showcased in Tab. 4. It demonstrates values for organizational citizenship behavior (Q2 = 0.136, Q2 effect = small), suggesting that organizational career growth has a limited impact on organizational citizenship behavior. This indicates that while there is a discernible influence, the magnitude of the effect is relatively small. Employees' commitment to going beyond their formal job requirements, contributing to the organization's success, and displaying positive citizenship behaviors may not be strongly driven by organizational career growth alone in the specific context of Saudi Arabia. In practical terms, banks in Saudi Arabia may need to consider additional factors, such as workplace culture, leadership styles, or employee engagement strategies, to enhance organizational citizenship behavior among their workforce.

Simultaneously, organizational career growth exerts a medium effect on both task performance (Q^2 = 0.218, Q2 effect = medium) and career (Q^2 = 0.281, Q2 effect = medium). This implies that advancements in one's career within the organizational structure significantly contribute to improved task performance and career sustainability. In the specific dynamics of the Saudi banking sector, the medium effect size implies that employees who undergo career growth are likely to demonstrate a moderate

enhancement in their task performance. This signifies that career growth is associated with increased competence and efficiency in carrying out job responsibilities. Additionally, the medium effect on career sustainability emphasizes the meaningful contribution of organizational career growth to the longevity and progression of employees' careers within the banking industry in Saudi Arabia.

This information is valuable for banks in Saudi Arabia as it emphasizes the importance of providing clear career growth opportunities to enhance both individual task performance and overall career sustainability. Organizations may find it beneficial to focus on structured career development programs and pathways to cultivate a workforce that is not only proficient in their roles but also has a sustained

Tab. 4: Model evaluation

Variables	SRMR	NFI	SSO	SSE	Q^2	Q2 effect
OCG	0.078	0.957				
OCB			1,070	924.20	0.136	Small
TP			1,206	942.60	0.218	Medium
CS			2,354	1,692.48	0.281	Medium

Note: SRMR – standardized root mean square residual; NFI – normed fit index; SSO – sum of squares of observations; SSE – sum of squares of errors; OCG – organizational career growth; OCB – organizational citizenship behavior; TP – task performance; CS – career sustainability.

Source: own (developed from SMART PLS-SEM)

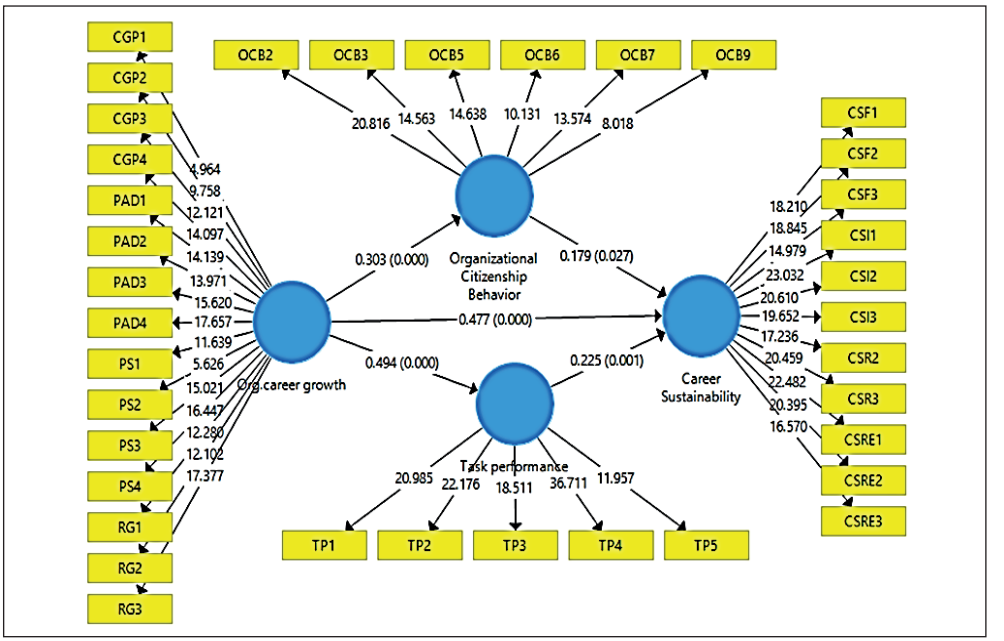

Fig. 1: Results of reflective model

Source: own (reflective model was developed by authors)

Tab. 5: Results of hypothesis testing

Hypothesis	Direct/indirect effect	Sample mean	STDEV	*T*-value	*p*-values	Bias	Bias corrected		Hypothesis supported
							5%	95%	
H1a	OCG → CS	0.478	0.069	6.929	0.000	0.001	0.339	0.614	Supported
H1b	OCG → OCB	0.325	0.079	3.824	0.000	0.015	0.130	0.443	Supported
H1c	OCG → TP	0.507	0.065	7.592	0.000	0.004	0.378	0.622	Supported
H2	OCG → OCB → CS	0.059	0.034	2.853	0.002	0.002	0.007	0.142	Supported
H3	OCG → TP → CS	0.111	0.039	2.872	0.004	0.000	0.050	0.210	Supported
H4	OCB → CS	0.186	0.085	2.110	0.035	0.007	0.028	0.363	Supported
H5	TP → CS	0.220	0.062	3.626	0.000	−0.005	0.112	0.359	Supported

Source: own (developed from SMART PLS-SEM)

commitment to long-term career growth within the banking sector.

3.2 Result of hypothesis testing

Fig. 1 and Tab. 5 display the outcomes of the hypothesis testing. The findings indicate that there is a favorable influence of organizational career growth (OCG) on employee's career sustainability (CS), thereby supporting *H1a*. Furthermore, the results also validate that OCG has an impact on organizational citizenship behavior (OCB; *H1b* supported) and task performance (*H1c* supported). Additionally, the results reveal that there exists a robust and direct correlation between OCG and CS (*H1a*), OCB and CS (*H4*), as well as TP and CS (*H5*).

To determine the possible mediation impact, the product coefficient approach (indirect effect) was utilized, and the significance of indirect effects was evaluated using bias-corrected confidence intervals (BCCI). This approach was based on the works of Hayes and Scharkow (2013) and Rasoolimanesh et al. (2021). Tab. 5 presents the results of the analysis, which supported the indirect but significant effects of organizational citizenship behavior on task performance and career sustainability (*H3*), as well as indirect but moderately significant effects on organizational citizenship behavior and career sustainability (*H4*), indicating a partial mediation impact. Furthermore, Tab. 5 shows that organizational citizenship behavior has a significant and indirect impact on career sustainability through both mediators, organizational citizenship behavior and task performance (*H2* and *H3*).

4. Discussion

The findings from the research indicate a positive relationship between organizational career growth (OCG) and employee's career sustainability (CS) and is aligned with several recent studies (Biswakarma, 2016; Vande Griek et al., 2020; Weng, 2018; Yang et al., 2015) predominantly focus on organizational career growth from the perspective of employees and how organizations can maximize their value. The four attributes of organizational career growth is evaluated on the career development opportunities and advancement provided by the current organization, including career goal progress, professional ability development, promotion speed, and remuneration growth which in turn contributes to career sustainability (Kaothan, 2018; McElroy & Weng, 2016). Research suggests that such growth initiatives foster a sense of psychological attachment among individuals towards their organization leading to increased belief and engagement with the organization (Nouri & Parker, 2013). Employee-driven career growth is seen as beneficial for workforces, as personnel are more likely to stay longer when their career aspirations align with organizational objectives (Yang et al., 2015). Organizational career growth also enhances the qualities, abilities, and talents of staff, preparing them for future job or position within the organization (Rawashdeh, 2013). Consequently, organizations that provide employees with access to career growth tools, resources, and processes tend to foster a sense of support and recognition among their workforce (Chen, 2016; Weng & McElroy, 2012). As a result,

individuals who have access to robust career growth opportunities tend to feel valued and supported by their organization, which in turn leads to career sustainability.

Our study reveals a positive correlation between four attributes of organizational career growth and career sustainability in the banking sector. However, diverse research findings highlight the influence of factors like professional ability development and rewards system (Gul, 2015); career goal progress and professional ability development (Nouri & Parker, 2013); professional ability development and remuneration growth (Lamba & Choudhary, 2013); and professional ability development, promotion speed, and remuneration growth (Van Osch & Schaveling, 2020). A previous study by Lamba and Choudhary (2013) demonstrates that organizational commitment is affected by various factors in different industries, such as remuneration growth and professional ability development in banking, career goal progress in academia, remuneration growth in hospitality, professional ability development in IT, and remuneration growth in manufacturing.

Theories like conservation of resources (Hobfoll, 1989) and career construction (Savickas, 2013) elucidate the link between organizational career growth and employee career sustainability. Thereby, supporting skill development fosters perceived value, leading to positive attitudes and job satisfaction. According to Bai (2018), a connection was found between organizational career growth and increased engagement in their study conducted in South China, emphasizing its importance for career sustainability. Weng et al. (2010) identify dimensions contributing to sustainability, supported by motivation theory, indicating that career advancement and skill development enhance focus for greater sustainability in Saudi Arabia. In addition, investigations done by Ordera et al. (2020) suggest that specific HR practices (employee task performance, organization career growth, and well-being) play a role in sustaining career growth and emphasize the direct impact of organizational commitment on long-term career sustainability.

The current investigation demonstrates the positive influence of organizational career growth on organizational citizenship behavior. According to Bagdadli and Gianecchini (2019), Turkish employees with career advancement opportunities exhibited increased organizational citizenship behavior. Similarly, a previous study by Bolino et al. (2013) demonstrated that US employees perceiving organizational support for career development displayed higher levels of organizational citizenship behavior. This research confirms that organizational career growth in Saudi banks enhances organizational citizenship behavior, fostering greater employee assistance, guidance, and voluntary task participation.

This study confirms that organizational career growth positively influences task performance in the Saudi Arabian banking sector. A research study conducted by Ingusci et al. (2021), establishes task performance as a mediator between organizational career growth and career sustainability. Grounded in the self-determination theory (Deci & Ryan, 2000), the study underscores how professional advancement and incentives enhance task performance among employees, supporting a positive impact of organizational career growth on task performance.

In the same way, the results of the current study also validated that organizational career growth impact on career sustainability, mediated by organizational citizenship behavior. Correspondingly, research by Cao et al. (2019), Gustari and Widodo (2022) and Qiu et al. (2020) also establishes a direct and indirect link between organizational justice and teachers' task performance, mediated by organizational citizenship behavior. The findings also support Freire and Pieta's (2021) conclusion that organizational citizenship behavior positively impacts career sustainability via its effect on job satisfaction. In this banking sector study, regulatory citizenship behavior moderately affects the relationship between career growth and career sustainability in Saudi Arabia. Furthermore, the study aligns with the social exchange theory, emphasizing the relationship between employees and the organization as a driver of organizational citizenship behavior (Al-Ghazali & Sohail, 2021).

Conversely, employees who perceive opportunities for career advancement within their organization are more inclined to engage in corporate citizenship activities. A study by Liu et al. (2022) involving 198 leader-member dyads in a Chinese high-tech firm revealed a positive association between employee career satisfaction and organizational citizenship behavior (OCB). Consequently, organizational

citizenship behavior is shown to influence job satisfaction, a key indicator of career longevity (Alhashedi et al., 2021), with this relationship mediated through the mechanism of organizational citizenship behavior (Azim, 2016). These findings accentuate the idea that career growth facilitated by corporate citizenship behavior positively impacts employee career sustainability in the banking sector of Saudi Arabia.

The results of the current study indicate that task performance has an impact on career sustainability. This result supports the findings by Cesário et al. (2022), which confirms that job performance is positively associated with career sustainability in the hospitality and tourism sector in Portugal. In addition to the findings by Udayar et al. (2021) in a study conducted in Switzerland, positive work events could contribute to career sustainability, that there is evidence of work-life spillover effects, making work events vital to consider when researching career sustainability, indicating that task performance might enhance the career sustainability, however, in Saudi Arabian banks, effective job performance, meeting sales targets, and providing excellent customer service were deemed essential for career sustainability. The study aligns with goal-setting and self-determination theories, emphasizing the impact of incentives, rewards, and feedback on task performance. The ability of Saudi banks to motivate and reward employees directly links to career sustainability and organizational growth. Consequently, task performance plays a pivotal role in shaping the career sustainability of banking sector employees in Saudi Arabia (Alsharah, 2014; Jehanzeb et al., 2012).

Conclusions

The study aimed to assess the impact of organizational career growth on career sustainability in Saudi Arabia's banking sector, with organizational citizenship behavior and task performance as mediators. It confirmed the significant influence of organizational career growth on career sustainability through these mediators, contributing novel insights to the literature. The findings offer valuable information for the Saudi Arabian banking sector, emphasizing how organizational career growth enhances overall performance and career sustainability within an organization.

This study holds significance for human resources managers in Saudi banks, offering practical insights. It emphasizes the crucial role of organizational career growth in achieving career sustainability among bank employees, aiding policymakers in the sector. Managers are encouraged to raise awareness about their subordinates' career growth, enhancing task performance and organizational citizenship behavior, thereby promoting overall career sustainability. Policy makers are advised to support practices fostering organizational career growth for enhanced performance and employee satisfaction in the banking sector.

Research limitations. The study's constraints involve the omission of certain subscales and amalgamating variables. Subsequent research should delve into distinct subscales such as career development, compensation, performance appraisal and managerial practices to advance employees organization career growth. Additionally, the cross-sectional nature of the research restricts causal inference, and the absence of longitudinal data hampers the ability to assess the long-term effects of organizational career growth.

Future research avenues may delve into aspects like workplace culture, mentoring schemes, and technological advancements within the banking domain. Exploring leadership styles, employee well-being programs, contextual performance, and industry-specific challenges' impact on career sustainability could enhance comprehension of factors affecting bank employees. Longitudinal studies on organizational career growth's efficacy pre- and post-individual experiences are suggested. Additionally, investigating causal relationships among organizational career growth and other variables is crucial for a deeper understanding, given the limited existing studies on this HR construct.

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The essence and barriers to the use of controlling in the practice of manufacturing enterprises

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Abstract: *The theory, but also examples from practice confirm the fact that the use of controlling in economic practice differs significantly in the context of understanding its essence. The ambiguity of the definition of controlling, two different thought concepts, the diversity of tools and approaches, but also other barriers prevent its use to a greater extent than this managerial approach would deserve. The current research is based on the understanding of the essence of controlling in German-speaking countries and is oriented towards a coordinated predictive management approach based on precise cost reports. The research question was aimed at identifying current use and barriers of controlling in manufacturing enterprises in relation to the understanding of its essence and impact of performance through a questionnaire survey and structured interviews with managers from 2021 to 2022. A population of 2,504 enterprises was addressed by means of stratified sampling. The chi-square goodness-of-fit test was used to test how well the characteristics of the research sample fit the final population. A total of 352 manufacturing enterprises formed the resulting sample representative – enterprise size and type of industry designated according to the European standard industry classification system. Methods of contingency analysis and interval estimates of the population proportion were used to test the stated hypotheses. The testing confirmed a dependence between the practical use of a broader scale of controlling tools and the performance of enterprises measured by the return on sales (ROS) indicator, as well as the difference in the perception of barriers to the implementation of controlling depending on the size of enterprises. Controlling with the assistance of software support of the management information system, with a detailed implementation process and precisely defined competencies of employees and controllable KPI, creates the potential to increase the complexity of management and performance of enterprises as well as the elimination of potential risks.*

Keywords: *Controlling, barriers, performance, return on sales.*

JEL Classification: *M11, M21, M40, P41.*

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Introduction

The current development of the market economy places increasing demands on enterprises in terms of adaptation and anticipation of changing conditions. The business environment is highly competitive with unexpected changes in the cost structure; thus, it is necessary to constantly adapt to market requirements while not forgetting about product innovations or the management system. Controlling is one of the concepts that have the potential to help a company address these challenges. Baldi (2020) and Wijethilake et al. (2018) state that innovations in connection with controlling are the driving force behind the development of each sector. However, there is no single definition of controlling. Not only in theory but also in practice, there are differences in the definition of the content of business controlling. The term controlling and its understanding vary according to individual authors and users. Even in academic circles, the opinion on its content is not uniform. Eschenbach (2004), an important expert and innovator in the field of controlling, defined its essence as managing a business as a complex system and at the same time trying to maintain control over this management system. An interesting definition of controlling is offered by Robbins and Coulter (2018), who define controlling as a process of precise monitoring, subsequent comparing with the desired condition, and correcting actions in the context of business performance. The practical use of controlling concept can be identified in many areas, especially in finances (Kozarevic & Vehabovic, 2020; Wang & Shailer, 2022), investments (Agarwal & Chaudhry, 2022; Sekścińska et al., 2021), a wide range of costs (Behúnová et al., 2022; Nowak, 2016), but also in personnel (Nowak et al., 2020; Voynarenko et al., 2020) and also in quality areas (Dahlgaard et al., 2019; Nowosielski, 2018). Many companies of different industries and sizes often perceive controlling and its application in practice. This diversity of perceptions consequently results not only in differences in the complexity of controlling use but also in their performance.

This work aims to find the answer to the research question and identify the current use and barriers of controlling systems in the praxis of manufacturing companies in the context of perception of its nature and its impact on performance. The research is focused on testing the dependence of the real use of controlling tools range and business performance, as well as on the direct identification of barriers and certain risks arising from the implementation of controlling. The orientation of the research thus fills a research gap in the given issue. The research seeks to initiate a discussion on the issue and to launch research and comparison of the authors' results in other European countries. The design of the study is structured chronologically. The review of relevant literature focuses on formulating the research question and research hypotheses. Subsequently, the methodology is presented, and based on the analysed results and discussion, certain recommendations, as well as limits and future orientations of research in the issue are proposed.

1. Theoretical background

In literature and practice, the essence of controlling is perceived differently with a number of recommended and used practical tools and approaches. According to the literary review, there are several definitions of controlling, which differ from author to author and their point of view. Often, however, such an individual view tends to predetermine a different meaning to controlling. In practice, every larger company applies a certain range of controlling tools in the management system. Still, due to its ambiguity in defining the content essence, there are several perspectives on what controlling should be principally focused on. Having joined many efforts to explain the essence of controlling (Baldi, 2020; Bieńkowska, 2021; Robbins & Coulter, 2018; Todorović et al., 2017; Tworek & Sałamacha, 2019), it can be stated that controlling is a managerial function that deals mainly with the financial management of the organisation in connection with its strategy. The essence of controlling is ideally defined by Gurčík (2018), who describes controlling as a specific concept of corporate management which connects areas of the planning and control process. The problems of ambiguity in the definition of controlling have their essence in the history and regional development of this managerial approach and impact its practical use. The history of controlling dates to the end of the 19th century when production became more complex and managers needed better information about their financial flows. As Goto et al. (2014) mention, especially in the USA, managers started to use systems for verification of production costs, which allowed them to monitor production

performance and costs of raw material, energy and labour in detail. In the 20th century, controlling became part of the management practice in various industries. New monitoring and cost management tools emerged during this time, such as budgeting and budgetary control. Otley et al. (2013) suggest that the process of improving the technology of data collection and analysis was noticeable, and already in the 1970s, controlling became an important part of corporate management in order to improve efficiency, reduce costs and increase the profitability of enterprises.

Today, controlling is a key part of managing organisations of all sizes and types because modern information technologies allow access to many data and give managers the possibility to quickly respond to changes in the business environment. In connection with controlling, there is often talk about the consistency of primary and secondary management coordination, which are interrelated and impact each other (Eschenbach, 2004). It is a primary and secondary coordination. Primary coordination integrates all business management activities, and secondary coordination creates a subsystem of information collection for decision-making in the planning system and implements the necessary control of the whole system. Based on historical development, it is possible to talk about two separate concepts of controlling, namely European and American, which impact the level of its practical use. The American approach focuses on quickly increasing profits and raising business performance. Emphasis is placed on innovation and market success, and benchmarking is used to set targets to improve performance. It is based on applying a wide range of financial indicators to measure performance, and ensure financial stability and productivity, especially in production, distribution and logistics. Financial performance indicators include profit, revenues, costs, return on investment and cash flow. As Dijkman (2019) and Belas and Rahman (2023) mention, the other performance indicators include productivity, efficiency, market growth rate, and competitive position. A different European approach often focuses on traditional values such as stability, responsibility and long-term sustainability. In its conception, the dominant factor is the principle of control and, in its connection, also the regulation and adoption of active measures. However, a strong focus on control can be a major weakness. However, the control should focus on monitoring and evaluating whether the implemented activities are carried out in accordance with plans and standards. These are reactive management processes aimed at correcting of errors and deficiencies based on the past. Controlling, however, in its comprehensive understanding, focuses mainly on active management and performance planning to meet goals per the corporate strategy. These are predictive management processes oriented toward the future. The context of focusing on past performance management vs. active future performance management provides fundamental differences between control and controlling. If the focus of controlling on the control itself can be eliminated, this European approach has great potential to be a managerial approach that builds the competitiveness and performance of enterprises, as well as an approach that provides important information in decision-making. As part of the European approach, it should be noted that the understanding of the essence is also different in individual countries. Controlling is perceived and used more comprehensively in countries with a German language base. Research by Janka and Günther (2020) and Zeman et al. (2018) support the claims that costs and precise controlling reports are the main essence of the practical use of controlling for predictive management processes and decision-making processes. As Mocanu (2014) states, controlling in countries with an English language base is mainly used from a management approach as an information bases for supporting decision-making processes. Current research is based on understanding the essence of controlling in these countries and, consequently on Slovak theory and practice in manufacturing enterprises. These enterprises have been chosen because, in the highly competitive environment, the application of innovations creates a high potential for the application of controlling principles.

In the application of controlling, several main tools are predominantly used to monitor and manage the performance of enterprises. Several authors (Konsek-Ciechońska, 2017; Lositska et al., 2022; Mazaraki & Fomina, 2016; Reta et al., 2018; Štefko et al., 2019) point out the following tools: budgeting, benchmarking, balanced scorecard, cash-flow management, risk management and, in particular, various tools for cost, calculation and benefit analysis.

The range of use of these tools was also part of the presented survey, which identified the essence, benefits, barriers, and future interest in using controlling in the practice of industrial enterprises. Research by Weber and Schäffer (2019) and Jánská et al. (2017) support the claims that controlling by using a range of tools can create benefits that many managers will appreciate. This managerial approach allows the identification and elimination of unnecessary costs and inefficient processes. It can also provide managers with important decision-making information in the areas of finance and investment. Controlling has the potential to create better collaboration between departments to adequately identify and evaluate risks and plan measures to eliminate them, as well as to contribute to greater employee motivation and performance through feedback on their assessment. The relationship between controlling vs. business performance is definitely interconnected. This is evidenced by the results of several studies (Bieńkowska, 2020; Fecková Škrabuľáková et al., 2019; Todorović et al., 2017; Weber & Schäffer, 2019). Some authors emphasise the very justification of the importance of financial control in their studies. Interesting examples are the authors' studies Kozarevic and Vehabovic (2020) and Khudyakova et al. (2019), but their research has not yet shown whether the using of a wide scale of controlling tools influences any indicative performance parameter.

Indeed, the application of control mechanisms in practical scenarios anticipates specific advantages, and at the same time, it also entails risks and barriers linked to its implementation. These challenges predominantly encompass financial and human resources considerations, along with the requisite technical expertise and analysis of pertinent data. Since controlling also requires a certain change in thinking and management philosophy, the fear of carrying out such change is a natural obstacle to its implementation. Another barrier is the fear that the implementation costs will outweigh the possible benefits of controlling. Incorrect analysis, large data volumes, and an over-emphasis of financial indicators that underestimate other aspects of performance, such as customer satisfaction or innovation, can also be problems. The research of some authors points individually to certain barriers to the implementation of controlling, but without further identification of their meaning and importance and possible causal factors (Sedliačiková et al., 2019; Teplická et al., 2020; Vacekova & Pavlik, 2013). In this research, the assumed and examined causal factor identifying barriers to the implementation of controlling was the size of enterprises. These assumptions became the basis for defining one of the research hypotheses.

Based on the presented information from the literature review, which confirmed the absence of conducted research and analyses in relation to the practical use of controlling, the following research question (*RQ*) was specified in the context of fulfilling the goal of the contribution:

RQ: What is the actual level of use and barriers of controlling in manufacturing enterprises in the context of perception of its practical essence?

2. Research methodology

The paper's main goal is to define the range of accessible controlling tools and barriers in Slovak manufacturing enterprises. The size of enterprises is examined as a factor determining the difference in the scale of the use of controlling in manufacturing enterprises. A possible effect is the different level of the company's performance indicator – return on sales (ROS).

For the collection of input data, the primary quantitative survey was the main method. Using the available Google form platform, the questionnaire survey was carried out in 2021 and additionally in 2022, and the data was also obtained through structured interviews with managers of selected industries of manufacturing enterprises. Targeted contacts were made with manufacturing enterprises whose number of employees was more than 10. These enterprises formed the basic population of industrial enterprises registered by the Statistical Office of the Slovak Republic. The enterprises were divided into three groups according to enterprise size, based on the European Commission Directive No. 2003/361/EC (European Comission, 2003) and into the industries based on the NACE codes (European Industry-Standard Classification System, section C – Manufacturing).

Yamane Taro's formula for a population of a finite size was used to identify the minimum sample size (Drew, 2022). For the population with a size of 2,504 enterprises (*N*) and

an acceptable error 0.05 (*e*) the minimum sample size of 345 enterprises (*n*) was derived.

$$n = \frac{N}{1 + N \cdot e^2} \quad (1)$$

$$n = \frac{2{,}504}{1 + 2{,}504 \cdot 0.05^2} = 345$$

To ensure the representativeness of the research sample, a stratified sampling pattern was followed. The questionnaire was distributed by individual e-mail contacts to 2,504 manufacturing enterprises with locations in Slovakia. Out of the total number of respondents, the return rate of the questionnaires represented 14.06%, which is 352 manufacturing enterprises. The structure of the research sample by industry is shown in Fig. 1. European industry standard classification system, section C Manufacturing (NACE codes) was used to denote individual branches of industry. In terms of enterprise size, the research sample consists of 173 small, 135 medium-size, and 44 large enterprises. The sample is shown in Fig. 1.

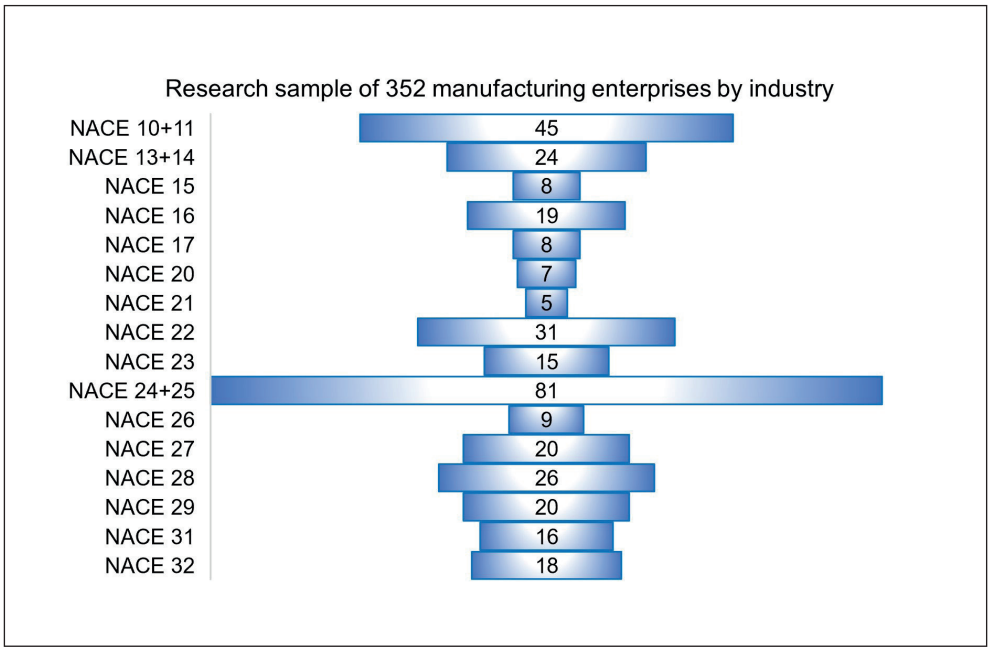

Fig. 1: Research sample by industry

Source: own

As a test of representativeness, the chi-square goodness-of-fit test was applied to check significant differences between the research and the target population. The test was also applied for contingency testing. The measure of dependence between two qualitative variables is based on the observed and expected frequencies (Kohler, 1988):

$$\chi^2 = \sum \frac{(f_0 - f_e)^2}{f_e} \quad (2)$$

The test statistics follow approximately chi-square distribution, assuming that only 20% of the expected frequencies are below five. In case of significant dependence, its strength

is assessed by the coefficient of contingency. It is an index with values from 0 (complete independence) to 1 (perfect dependence).

Interval estimates for population proportion with 95% confidence were calculated following the formula (Lind, 2020):

$$p - u_{\frac{\alpha}{2}} \cdot \sqrt{\frac{p(1-p)}{n}} < \pi < p + u_{\frac{\alpha}{2}} \cdot \sqrt{\frac{p(1-p)}{n}} \quad (3)$$

Statistica 12 software was used for data processing. When testing hypotheses, a significance level of 0.05 was chosen as a decision rule for comparability with similar studies. The tables containing the output analyses were edited in Microsoft Excel for better clarity.

Based on the research question identified at the end of the Theoretical background, the authors formulated the following hypotheses:

H1: The scale of use of controlling tools in manufacturing enterprises affects their performance level (measured by the ROS indicator).

H2: The perception of barriers to the implementation of controlling varies according to the size of manufacturing enterprises.

3. Research results and discussion

The literature review describes the essence of controlling, emphasising the scope of use of controlling tools, certain benefits, and barriers preventing its implementation. However, the published research does not include a more detailed analysis of the impact of understanding and using the essence of controlling on performance. This

Tab. 1: The test of representativeness by industry of research sample

Industry	Share of industry in the population (%)	$\chi^2 = 6.69$; sv = 15; $p = 0.966$			
		O_i	E_i	$O - E$	$(O - E)^2 / E$
NACE 10 + 11	12.03	45	43.30	1.70	0.07
NACE 13 + 14	7.11	24	25.02	−1.02	0.04
NACE 15	1.76	8	6.19	1.81	0.53
NACE 16	4.91	19	17.29	1.71	0.17
NACE 17	2.00	8	7.03	0.97	0.13
NACE 20	2.08	7	7.31	−0.31	0.01
NACE 21	0.68	5	2.39	2.61	2.85
NACE 22	8.99	31	31.63	−0.63	0.01
NACE 23	4.55	15	16.03	−1.03	0.07
NACE 24 + 25	23.88	81	84.06	−3.06	0.11
NACE 26	2.84	9	9.98	−0.98	0.10
NACE 27	6.03	20	21.23	−1.23	0.07
NACE 28	8.63	26	30.36	−4.36	0.63
NACE 29	6.23	20	21.93	−1.93	0.17
NACE 31	3.31	16	11.67	4.33	1.61
NACE 32*	4.71	18	16.59	1.41	0.12
Total	100.00	352	352.00	0.00	6.69

Note: * specific NACE 32 also includes industry NACE 5, 7, 8, 9, 18, 19; *O* – observed frequencies; *E* – expected frequencies.

Source: own

is also the basic reason for the interest in the issue in question in the Slovak business environment of manufacturing enterprises. As part of the primary survey, a total of 2,504 manufacturing enterprises within the population in the Slovak business environment were addressed. A final data set of 352 manufacturing enterprises entered the study as a representative subset of the target population with a margin of error of 5%. The representativeness of research sample by industry was tested by the chi-square goodness-of-fit test. Results of testing presented in Tab. 1 indicate that the distribution of single industries in the sample is in very good accordance (p = 0.966) with the distribution in the target population.

The representativeness of the research sample with the population according to the size of the company was tested in a similar way. Population and sample distribution according to size of enterprises is presented in Fig. 2. The observed differences are not significantly different from the target population ($\chi 2$ = 0.21, df = 2, p = 0.898). Also, according to the size of the enterprise, the assumption of representativeness is met.

The partial results of the given research confirmed that the approximate share of Slovak

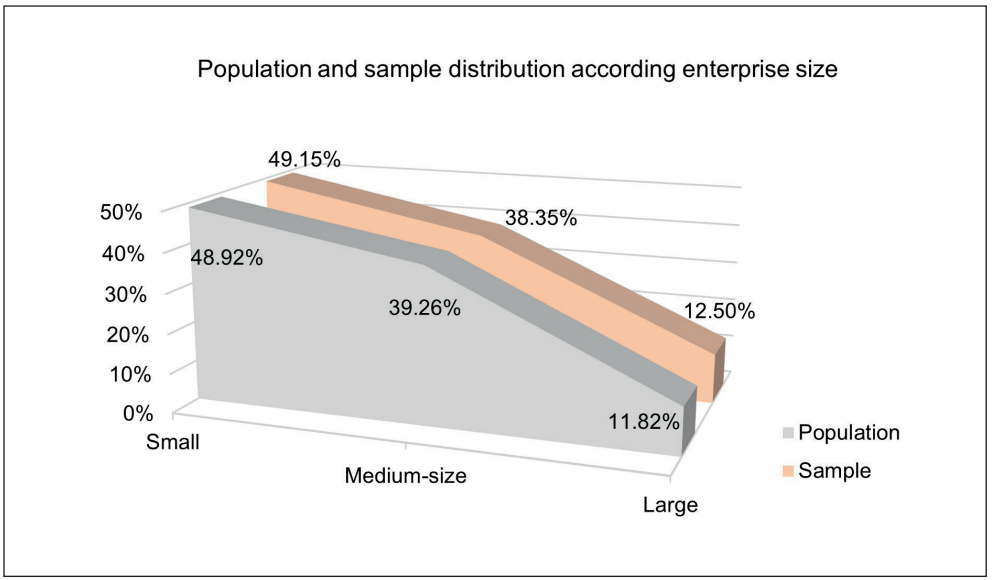

Fig. 2: Representativeness of research sample by enterprise size

Source: own

manufacturing companies that apply controlling approaches in their practice is at the level of 50%. The presented results of the study by Potkany et al. (2022) confirmed that controlling tools are much more often used in the practice of large and medium-sized enterprises in industries with a higher level of added value (NACE 26, 28, 29).

The interpretation of research findings is organised within the formulated hypotheses, with a discussion separately evaluating each of these hypotheses and research questions. Based on the understanding of the essence of controlling in German-speaking countries focused on reporting and costs, the following controlling tools and approaches were analysed in the research: compilation and control of plan (production, revenues and costs) compared to a plan/reality, control of the quality and quantity of production, control of cost consumption, flexible pricing of products, use of benchmarking principles, and also budgeting.

If a company uses three or more controlling tools and approaches, it is possible to state on wider scale. The proportion of enterprises that apply less than three controlling tools was estimated in the four groups of Slovak manufacturing enterprises according to the indicative parameter of company performance measured by the level of ROS. From the results in Tab. 2, it can be observed that the proportion of enterprises that do not apply controlling tools is over half in the first two groups. In the group with values ROS up to 2.5%, the estimated population proportion is even from 81% to 91%. In the group of enterprises with values of ROS from 2.6% to 5%, the estimated population proportion is from 28% to 49%. In the last group with values of ROS more than 5% is the estimated population proportion of enterprises not applying a wider range of controlling tools maximum of about a third (from 8% to 33%).

The relationship between the insufficient use of controlling tools and the level of return on sales achieved was tested using Pearson's chi-square test at the 5% significance level. The final results of the contingency testing are presented in Tab. 3. The contingency was evaluated as significant ($p = 0.000$) with a moderate strength of 0.46. These results confirmed the first hypothesis (*H1*). The results of studies by some authors, such as Bieńkowska (2020), Fecková Škrabuľáková et al. (2019) and also Todorović et al. (2017), confirmed a positive relationship between controlling and business performance. The authors essentially agree that controlling can be an effective tool in monitoring and managing financial flows within a business. It can contribute to the creation of a transparent environment that enhances investor confidence. Moreover, it particularly supports flexible adaptation to business changes and trends within decision-making processes. However, these works did not examine in detail the scale of tools for the practical use of controlling. As Kral (2018) mentions, controlling with its approaches and tools represents a conceptual foundation based on the plan-control-report framework, enabling the enhancement of business process effectiveness as well as overall performance. Similar conclusions were presented in their study by Weber and Schäffer (2019), who emphasised that improving forecasting based on controlling data analysis provides a foundation for accurate planning of future steps and decisions. This can minimise business risks and contribute to long-term sustainability in performance. The work of Eschenbach (2004) also discusses the relationship of controlling, its broader understanding of its essence and, in particular, its real use in the context of increasing the performance and competitiveness of enterprises.

Tab. 2: Insufficient use of controlling tools in the population of manufacturing enterprises according to return on sales (95% interval estimates)

Return on sales	*p* (point estimate of proportion; %)	*n* (sample size)	95% interval estimate	
			Lower limit (%)	Upper limit (%)
Lost	64.58	48	51	78
Up to 2.5%	86.03	179	81	91
From 2.6% to 5%	38.37	86	28	49
More than 5%	20.51	39	8	33

Source: own

Tab. 3: Results of Pearson chi-square test for hypothesis *H1* (contingency between variables insufficient use of controlling tools and return on sales)

Chi-square test	Degree of freedom	*p*-level	Contingency coefficient
94.480	3	0.000	0.460

Source: own

Tab. 4: **Results of contingency analysis for hypothesis *H2* (individual barriers of controlling versus enterprise size)**

Barriers	Chi-square test	Degree of freedom	*p*-level
The need for increased funding and a long time for implementation	26.96	2	0.000
The benefits of use will be less than the cost of implementation	11.00	2	0.004
The lack of technical equipment and skills	54.40	2	0.000
Non-acceptance by employees	8.62	2	0.013
Fear that the implementation will not bring the expected effect	2.94	2	0.230

Source: own

Tab. 5: **Perception of potential barriers for controlling implementation in the population of Slovak manufacturing enterprises according to company size (95% interval estimates)**

Barriers to implementation of controlling	Enterprise size	*p* (point estimate of proportion; %)	95% confidence interval	
			Lower limit (%)	Upper limit (%)
The need for increased funding and a long time for implementation	Small	36.42	**29**	**44**
	Medium	18.52	12	25
	Large	2.27	0	7
The benefits of use will be less than the cost of implementation	Small	27.75	**21**	**34**
	Medium	15.56	9	22
	Large	9.09	1	18
Lack of technical equipment and skills	Small	45.09	**38**	**53**
	Medium	13.33	8	19
	Large	2.27	0	7
Non-acceptance by employees	Small	9.25	**5**	**14**
	Medium	2.96	0	6
	Large	0.00	–	–

Note: Values in bold – the highest values among all interval estimates.

Source: own

According to Jánská et al. (2017), controlling is able to activate measurable benefits that many managers will appreciate. The positive relationship between the utilisation of a broader range of controlling tools and financial benefits, particularly performance, is indeed evident. This correlation was confirmed by the findings of the study conducted by Kozarevic and Vehabovic (2020) and also by Khudyakova et al. (2019), at least within the domain of financial controlling tools. Despite the relatively wide range of benefits, not all of them are fully utilised in practice. There are several barriers that prevent this from happening. In the context of the second research hypothesis, the relationship between individual barriers to controlling and the size of manufacturing enterprises was tested (Tab. 4). The company's size can

significantly influence the perception of four of the five examined barriers ($p < 0.05$). Dependence was not observed only in the case of fear that the implementation would not bring the expected effect ($p = 0.230$).

A more detailed examination of dependence based on calculations of residual frequencies showed, that the given barriers are obstacles to using of controlling, mainly in small manufacturing enterprises. This fact can also be observed in Tab. 5 based on 95% interval estimates of the population proportion of enterprises for which the given barriers represent a problem in the implementation of controlling. The highest values among all interval estimates are observed in the population of small-size manufacturing enterprises (bold text in Tab. 5). The lack of technical equipment and skills is the most frequent problem (from 38% to 53%) in the implementation of controlling for small-size enterprises.

By comparing the results of available research dealing with the issue in question, it is possible to conclude that several authors have also partially dealt with identifying barriers to the implementation of controlling. Verburg et al. (2018) and Čambalíková and Mišún (2017) state that a significant barrier is the time to prepare the implementation, the necessary finances and changes in the software support for reporting, but especially the resolution of the issue of the importance and orientation to the different levels of control. Similar research aimed at analysing the interaction between the enablers and barriers to successful project control system was carried out by Jawad and Ledwith (2021). In the research, several barriers preventing the successful implementation of controlling principles were identified, especially the lack of standard processes, vague contract deliverables, disparate control system between owner and contractor and lack of information communication. The study by Sedliačiková et al. (2019) deals with the identification of barriers to the implementation of controlling in the conditions of industrial production in the woodworking industry. Vacekova and Pavlik (2013) identified several problems of controlling implementation (need and lack of funds for implementing control systems, insufficient management support, and reluctance of employees to accept changes in terms of understanding the essence of controlling). The problem lies

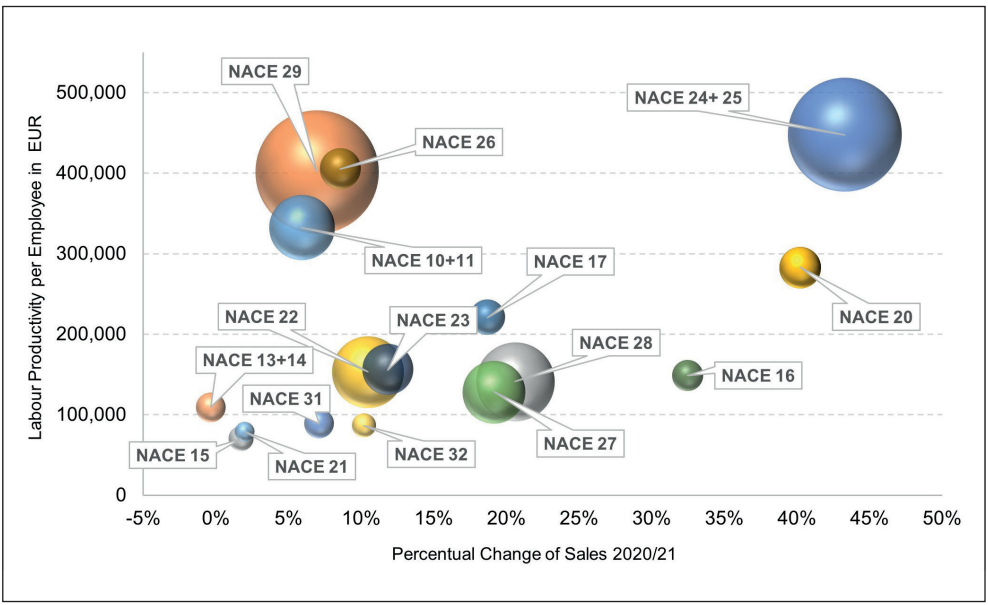

Fig. 3: **Value added and changes in sales according to labour productivity per employee in Slovak manufacturing sector in 2021**

Source: own

in the fact that none of the available studies have examined the causal relationship between the identification of implementation barriers and other variables. This represents a significant research gap, which the informational database and the results of the presented study aim to support.

Through the given estimates (Tab. 5), it is possible to state that in the population of medium-sized enterprises, the most common barrier (from 12% to 25%) is the need for increased funding and a long time for implementation. Large-size enterprises are showing some concern (from 1% to 18%) that the benefits of use will be less than the cost of implementation. From the presented facts, it can be stated that the perception of barriers also differs in the size relation of enterprises, and therefore, hypothesis *H2* can be confirmed. In particular, large enterprises and partly medium-sized manufacturing enterprises, often with a mixed or foreign capital structure and know-how in the field of controlling, do not perceive possible barriers to implementation as fundamentally as small enterprises. Of course, the industry also plays a role, as well as the possible level of its technology. These enterprises also show higher sales, labour productivity per employee and added value indicator. The data in Fig. 3 present arguments that support this statement. Fig. 3 visually, with a three-dimensional view, presents information on the change in sales in 2021, expressed as a percentage compared to 2020. At the same time, the analysed companies are classified according to labour productivity per employee. Crucial is the fact that the size of the circle characterises the share of value added by the industry within the whole industry. The information from the yearbook of industry, presented by the Statistical Office of the Slovak Republic (2022), can be confirmed that the highest percentage change in sales with a focus on the value added was recorded in the following industries: the manufacture of basic metals or fabricated metal products (NACE 24, 25) and also manufacture of chemicals (NACE 20). Taking into account the growing level of labour productivity per employee, these sectors apply the highest rates of use of controlling tools and approaches in manufacturing enterprises and have a dominant representation in the categories of medium and large enterprises: manufacturing of motor vehicles (NACE 29), manufacturing of computer products (NACE 26), and manufacturing of food products (NACE 10). These survey results also support the validity of both hypotheses, i.e., the real dependence between the range of application of controlling approaches and the business performance, as well as the dependence on the perception of barriers preventing the implementation of controlling and their size.

Conclusions

The main goal of this study was to identify current use and barriers of controlling at the praxis of manufacturing companies in Slovakia and their potential impact on the business performance. In a broader context, a research gap has been identified in this area, which indicates a lack of studies explaining the impact of the scope of controlling tools on performance, as well as the perception of implementation barriers depending on the size or industry of industrial enterprises. Based on the results presented in the previous sections of this paper, it can be concluded that this study supports the theory of a positive relationship between the utilisation of a broader range of controlling tools and corporate performance, parameterised by ROS indicators. Using the methods of contingency analysis, the moderate strength of the dependence between the application of a range of controlling tools and the business performance measured by ROS was confirmed. The sector analysis was mainly dominated by large and also partially medium-sized enterprises with a higher level of value-added and labour productivity per employee. At the same time, these enterprises are also more resistant to the perception of potential barriers preventing the implementation of controlling in practice, what was derived on the basis of interval estimation theory. The lack of technical equipment and skills of potential users of controlling approaches and the fear of need for increased funding and a long time for implementation were perceived as the most serious barriers. However, examples of good practice on the comprehensive use of controlling in the corporate management system with the assistance of the use of software support of the management information system prove that barriers and risks can be eliminated. Nevertheless, the implementation process should also include a specification of the expected benefits, a detailed schedule with exactly defined competencies of responsible employees, and controllable key

performance indicators. The results of the research also partially confirmed the results of research conducted by other authors on the impact of controlling on business performance in general (Bieńkowska, 2020; Fecková Škrabuľáková et al., 2019; Weber & Schäffer, 2019). Research by Janka and Günther (2020) suggest that particular emphasis of controlling was placed on supporting the essence for planning and coordinating subsystems. Zeman et al. (2018) support the argument that controlling coordinates the management system to address various types of decision-making tasks. These conclusions are consistent with the recommendations of this paper.

The study has identified specific limitations that suggest avenues for further potential research. The limiting factor of this study is the implementation of this research on a national scale of manufacturing enterprises in Slovakia, which makes it difficult to generalise the results for a wider global environment. The presented results may initiate a discussion on the issue in a broader context for other authors and in other European countries. Future research will therefore focus on efforts to disseminate source data in a wider European area as well as other than industrial sectors. The research plan is focused on the possible identification of dependencies of other controlling variables (perception of benefits, complexity of controlling reports, targeted focus on the essence of controlling) for some alternative but available indicators of business performance. The current global crisis has emphasised the need to continue exploring and raising awareness of the essence, effects, and barriers of controlling due to the challenges and uncertainties in the business environment. This includes the requirement to identify cost savings, reassess investments, and make other critical decisions.

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Multiscale non-linear tale risk spillover effect from oil to stocks – The case of East European emerging markets

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Abstract: *This paper investigates the multiscale non-linear risk transmission effect from Brent oil to eleven European emerging stock markets. Dynamic extreme risk time series are created using the FIAPARCH-CVaR approach. The MODWT transformation is applied to make three wavelet details that represent different time horizons. In the final step, the MODWT time series are fitted into the Markov switching model to examine the spillover phenomenon. The results indicate that the Czech and Hungarian stock markets endure the spillover effect in crisis regime in the short term, probably because these markets are among the most efficient emerging European markets. On the other hand, a relatively high spillover effect is found in a peaceful rather than a crisis regime in the case of Poland. This is probably because the Polish index lists almost 300 stocks, which means that oil shocks disperse to a large number of different industry sectors. In small and less developed markets, such as Estonia, Slovenia, Bulgaria, and Croatia, a high spillover effect exists in a tranquil regime because these countries have high oil consumption per capita. Lithuania and Latvia do not report the spillover effect in the short run, while this is true for all time horizons in the case of Slovakia.*

Keywords*: Extreme risk spillover effect, conditional value-at-risk (CVaR), wavelet methodology, Brent oil, stock markets.*

JEL classification*: C58, G12, G32.*

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Introduction

Oil is the key strategic energy source that runs corporate businesses around the world. This means that the oil market and stock markets are inevitably interconnected, where a plethora of literature confirmed this relationship (Abakah et al., 2023; Aydin et al., 2022; Mensi et al., 2022a). Tian et al. (2022) list several economic conduits that connect oil and stock markets. One of the most important and most detrimental channels is the supply-side shock effect passed on to the effect of inflation. In other words, an increase in the price of crude oil directly affects production by increasing

the marginal costs of new products. As a result, inflation increases due to rising oil prices. This lowers spending power of consumers and reduces the profits of companies, which causes stock prices to fall. On the other hand, the so-called aggregate-demand effect also occurs, where purchasing power can be transferred from oil-importing countries to oil-exporting countries. This results in a rise of stock prices in oil-exporting countries and a fall of stock prices in oil-importing countries.

The recent crises, such as the COVID-19 pandemic and the ongoing war in Ukraine, have inflicted unprecedented shocks to oil and stocks (Gemra et al., 2022). These developments intensified the efforts of academics, investors, and commodity traders to better understand the interlinks between oil and stock markets because they have important repercussions for the stability and successful operation of companies. The left plot in Fig. 1 clearly shows that the two crises had a very deep impact on the Brent oil market. Travel restrictions and lockdowns caused a steep drop in global oil demand, provoking oil prices to fall to 20 USD per barrel in April 2020. On the other hand, the war in Ukraine pushed the price of oil to over 120 USD per barrel in May 2022. These happenings induced huge risk in the oil market, as can be seen in the right plot (Fig. 1), part of which has certainly been transferred to stock markets.

The paper tries to estimate univariate risk transmission from Brent oil to eleven stock indices of East European economies, which are members of the EU (Poland, Czechia, Hungary, Slovakia, Lithuania, Latvia, Estonia, Slovenia, Romania, Bulgaria and Croatia). Risk transmission between the markets is important to study because the oil-stock risk interdependence is growing stronger, whereas the risk transmission mechanism is becoming more complex due to the deepening of commodity financialization and global financial integration (Wen et al., 2022).

In order to measure extreme risk, researchers usually consider value-at-risk (VAR) to be the most famous measure of downside risk. However, one of the major issues of the VaR model is its inability to measure the losses beyond the threshold amount of VaR. Rockafellar and Uryasev (2002) tried to resolve this drawback by proposing the parametric conditional VaR (CVaR), which can address losses beyond VaR. In other words, the parametric CVaR calculates the average loss of the worst returns taking into account a certain level of probability (Živkov et al., 2021). In order to properly calculate dynamic CVaR, empirical time series need to be independently and identically distributed, which is usually not the case because daily time series are prone to autocorrelation, heteroscedasticity, volatility clustering, leverage effects, fat tails, and long memory. With the aim to better recognize the idiosyncratic features of the time series, we use the FIAPARCH model because this model produces the most accurate VaR and expected shortfall, according to Alkathery et al. (2022). Student *t* distribution is utilized to fit

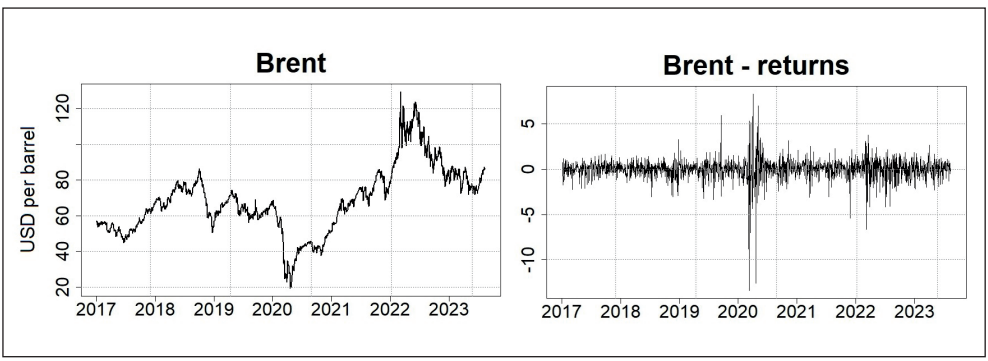

Fig. 1: Empirical dynamics of Brent oil

Source: own

the fat tails of the empirical time series. Accordingly, the white noise residuals of this model are used to create the dynamic CVaR time series of Brent oil and stock indices.

Jin et al. (2023) assert that oil price shocks can impact stock prices in different time horizons, which means that risk spillovers can be observed at multiple time scales. This concept is also important from the aspect of different market participants. In other words, short-term agents, such as arbitrageurs and speculators primarily look at temporary happenings, such as unusual events and socio-economic news (Rösch et al., 2022). Fund managers, as mid-term investors, are concerned to medium-term market developments (Barunik & Krehlik, 2018). On the other hand, policymakers and large financial institutions, such as insurance companies and pension funds, are keen to know how the macroeconomic environment and fundamental factors function (Fong et al., 2022). To address the issue of the multi-frequency spillover effect, we use the maximum overlap discrete wavelet transformation (MODWT) methodology in order to generate the wavelet signals of different frequencies that personify short-, medium- and long-term horizons.

In the final stage of the research process, we embed eleven wavelet-based oil-stock pairs into the Markov switching (MS) model in a pairwise manner in order to investigate the unidirectional oil-stock causality. This model is used to capture shifts in economic or financial data when they cannot be fully explained by a single set of parameters and assumptions. Since we cover a relatively long time span, which includes the two crises, it is logical to hypothesize that the relationship is non-linear. In particular, assuming the presence of a non-constant relationship, we allow stock indices to rely on the two independent state regimes that shape the conditional mean process. Basher et al. (2016) explain that the Markov switching model uses the information from the varying regime-switching probabilities of being in a particular regime to allow time-varying causality across regimes. From this aspect, we can get information in which time the horizon extreme risks from the oil market have the greatest impact on the stock market and in which regime this happens.

The existing literature found mixed results regarding the oil-stock risk spillover relationship without reaching a consensus, which indicates the complexity of this phenomenon. Ahmed and Huo (2021) utilized the tri-variate VAR-BEKK-GARCH model to examine the dynamic nexus among commodity markets, the Chinese stock market and global oil price. They found bidirectional shocks spillovers between oil and stock markets but unidirectional volatility spillovers from the oil market to the Chinese stock market. Jiang et al. (2022) used the long-memory Copula-CoVaR-MODWT method to document the risk spillovers from oil to BRICS stock markets, addressing both time and frequency domains. They showed that significant risk spillovers exist with time-varying and heterogeneous characteristics. The paper of Okorie and Lin (2022) researched the information spillovers in return and volatility, considering the two crude oil markets (Brent and WTI) and the Nigerian stock index (NSE) using the asymmetric VAR-MGARCH-GJR-BEKK model. They found a bi-directional volatility spillover effect between the crude oil markets and the NSE index, and significant asymmetric shocks. Chan and Qiao (2023) investigated the volatility interdependencies between oil and stock markets, taking into account the WTI oil price and ten S&P500 sub-indices. According to their results, demand shocks to stock markets and oil cause much stronger spillover effects than supply shocks.

The main research question of the paper and its contribution to the existing literature pertains to whether and how extreme risk from the Brent market spills over to the stock markets of Central and Eastern European countries. This type of research has never been done before for this group of countries, to the best of our knowledge, and this is our motive to do this study. Contribution is also reflected in the fact that the spillover effect is observed from the aspect of various time horizons, which deepens the understanding of this phenomenon. The use of elaborate methodologies contributes to the reliability of the results, which is also a relevant characteristic of this paper.

Besides the introduction, the rest of the paper is structured as follows. The first section explains the used methodologies – the FIAPARCH model, wavelet transformation, and Markov switching model. The second section introduces the research data and preliminary findings. The results and discussion are presented in the third section. The last section is reserved for conclusions.

1. Used methodologies

1.1 Long memory GARCH and dynamic CVaR

If a time series has a slow declining autocorrelation function (ACF), then it has the long memory property, as Ding and Granger (1996) explained. It is said that time series is a stationary long-memory process if the autocorrelation function (ACF), ρ(*k*) behaves as $\rho(k) \approx c|k|^{2d-1}$ as $|k| \to \infty$, where 0 < *d* < 0.5, and *c* is a positive constant. The ACF has a very slow rate of decline to zero as *k* strives to infinity and $\sum_{k=-\infty}^{\infty}|\rho(k)| = \infty$. Long memory property can be modelled by the fractionally integrated GARCH (FIGARCH) model, which is an extension of the classical GARCH model. It is used to capture long-memory persistence in volatility, which means it accounts for the fact that volatility tends to persist over time. In the traditional GARCH model, volatility is modeled using lagged squared errors and lagged conditional variances. However, these models assume that volatility persistence is finite. In contrast, the FIGARCH model allows for the possibility of infinite persistence, meaning that shocks to volatility can have a lasting impact on future volatility.

Some papers found the long memory process in energy commodities and stocks (Chkili et al., 2021; Youssef et al., 2015), so we apply the fractional integrated asymmetric power ARCH model – FIAPARCH of Tse (1998) in order to address this issue. The mean equation includes the first-order autoregressive term, which is enough to deal with autocorrelation. Student *t* distribution tackles fat tails in the empirical distributions. The mean and FIAPARCH(*p*, *d*, *q*) specifications look as follows:

$$y_t = C + \Theta y_{t-1} + \varepsilon_t;\ \varepsilon_t \sim St(0,\ \sigma_t,\ \nu) \tag{1}$$

$$\sigma_t^{\delta} = \omega[1 - \beta(L)]^{-1} + \\ + \{[1 - \beta(L)]^{-1}\ \alpha(L)(1-L)^d\}\ (|\varepsilon_t| - \gamma\varepsilon_t)^{\delta} \tag{2}$$

where: ω is constant; *L* denotes the lag-operator; γ, δ and *d* are the model parameters. Parameter γ is the leverage coefficient, where γ < 0 means that positive shocks affect volatility more than negative shocks and vice-versa. Symbol δ stands for the power term parameter, and it has finite positive values. When γ = 0 and δ = 2, the FIAPARCH process becomes FIGARCH(*p*, *d*, *q*) model. *d* represents the fractionally differencing parameter measuring the persistence of shocks to the conditional variance. FIGARCH(*p*, *d*, *q*) model permits an intermediate range of persistence, where *d* parameter can be found in the scope: 0 < *d* < 1. When *d* = 0, FIGARCH model reduces to ordinary GARCH, whereas when *d* = 1, FIGARCH is equivalent to integrated GARCH or IGARCH.

After the estimation of the FIAPARCH models, we use the fitted residuals to calculate the dynamic CVaR time series at 5% probability level. CVaR measures the average amount of loss that investor could have in one day with a certain probability. CVaR is the integral of VaR, where VaR can be expressed as $VaR_{\alpha} = \hat{\mu} + Z_{\alpha}\hat{\sigma}$. $\hat{\mu}$ and $\hat{\sigma}$ denote the estimated mean and standard deviation of a particular asset, respectively, while Z_{α} is the left quantile of the normal standard distribution. CVaR is calculated as in Equation (3):

$$CVaR_{\alpha} = -\frac{1}{\alpha}\int_0^{\alpha} VaR(x)dx \tag{3}$$

1.2 MODWT transformation

After constructing the dynamic CVaR time series of all assets, we use wavelet methodology to build three wavelet details representing short-, medium- and long-term horizons. On the theoretical basis, the wavelet operates with the two elementary wavelet functions: mother wavelet (ψ) and father wavelet (ϕ). Father wavelets depict the low frequency or smooth parts of a signal, having an integral of 1. On the other hand, mother wavelets explain high-frequency components with an integral equal to 0. The father ($\phi_{J,k}(t)$) and mother ($\psi_{J,k}(t)$) wavelet functions can be presented in the following way:

$$\phi_{J,k}(t) = 2^{\frac{-J}{2}}\phi\left(\frac{t-2_k^J}{2^J}\right),\ \ \psi_{J,k}(t) = 2^{-J/2}\psi\left(\frac{t-2_k^J}{2^J}\right) \tag{4}$$

where: symbol 2^J stands for the scale factor, while 2_k^J is the translation or location parameter.

For the wavelet computation process, the study uses the non-orthogonal wavelets, known as the maximum overlap discrete wavelet transformation (MODWT), which has highly redundant and non-orthogonal transformation characteristics. Decomposed signals in the MODWT framework are presented as follows:

$$S_{J,k} \approx \int f(t)\phi_{J,k}(t)dt \tag{5}$$

$$D_{J,k} \approx \int f(t)\psi_{j,k}(t)dt, j = 1, 2, ..., J \quad (6)$$

where: symbols $S_{J,k}$ and $D_{J,k}$ denote the fluctuation and scaling coefficients, respectively, at particular j^{th} level, which decomposes empirical signal or time series in terms of a specific frequency (trending and fluctuation components).

According to Equations (5–6), an empirical time series $y(t)$ can be expressed in terms of those signals as:

$$f(t) = \sum_k S_{J,k}\,\phi_{J,k}(t) + \sum_k D_{j,k}\,\psi_{j,k}(t) + \\ + \sum_k D_{j-1,k}\,\psi_{j-1,k}(t) + ... + \sum_k D_{1,k}\,\psi_{1,k}(t) \quad (7)$$

1.3 Markov switching model

The scale-dependent Markov switching model was originally developed by Goldfeld and Quandt (1973), and we are using it to research the non-linear extreme risk spillover effect between Brent oil and stock markets in different time horizons. The Markov chain governs the Markov switching model, where the future state depends only on the current state and the probability of a particular value (Rosen et al., 2023). In this paper, two states are assumed (S_t = 1, 2), where S_t is an unobserved state variable. S_t = 1 depicts increased volatility in the stock markets, while state S_t = 2 refers to calm market conditions. Besides the switching process in the mean, we also permit the variance of the error term to switch between the states. The unidirectional wavelet-based Markov switching estimation equation looks like as follows:

$$SI_{i,t}^{j} = c_{st}^{j} + \phi_{st}^{j} OIL_t^{j} + \varepsilon_t^{j};\ \varepsilon_t \sim N(0, \sigma_{st}^2) \quad (8)$$

where: *SI* denotes the dynamic CVaR of a particular stock index *i*, and OIL is the dynamic CVaR of Brent time series. Both constant *c* and the spillover parameter ϕ are scale-dependent, where the wavelet scale is labelled by the symbol *j*. The Markov chain is unobservable by definition, which means that probabilities need to be included in order to estimate an output. In other words, changing regimes is not governed deterministically but with a certain probability (Qian et al., 2022). Therefore, the unobserved state variable S_t follows a two-state Markov process with transition probabilities as in Equation (9):

$$\left.\begin{array}{l} P(S_t = 1 \mid S_{t-1} = 1) = p_{11} \\ P(S_t = 1 \mid S_{t-1} = 2) = p_{12} \\ P(S_t = 2 \mid S_{t-1} = 1) = p_{21} \\ P(S_t = 2 \mid S_{t-1} = 2) = p_{22} \end{array}\right\} \begin{array}{l} \text{where} \\ p_{11} + p_{12} = \\ = p_{21} + p_{22} = 1 \end{array} \quad (9)$$

The Markov switching model is estimated by the maximum likelihood function, where the filtering procedure of Hamilton (1990) and the smoothing algorithm of Kim (1994) are used.

2. Dataset and preliminary findings

The paper uses daily data of Brent spot oil and eleven stock market indices from the countries of Central and Eastern Europe: WIG (Poland), PX (Czechia), BUX (Hungary), SAX (Slovakia), OMXV (Lithuania), OMXR (Latvia), OMXT (Estonia), SOBITOP (Slovenia), BET (Romania), SOFIX (Bulgaria) and CROBEX (Croatia). All assets are collected from the stooq.com and investing.com websites. The sample covers the period between January 2017 and August 2023, which includes relatively calm and turbulent periods before and during the pandemic and the war in Ukraine. All indices are separately combined and synchronized with Brent oil. Also, all time series are transformed into log returns (r_i) according to the expression: $r_i = 100 \times \log(P_{i,t}/P_{i,t-1})$, where P_i is the price of a particular asset. It should be said that SAX is the least liquid index, while Bratislava SE is the least developed stock exchange (Baele et al., 2015), which means that there was no trading at all on a significant number of days. This is reflected in the modeling and construction of extreme downside and upside risks. In other words, the created dynamic downside risk time series of SAX are not smooth as in the case of other indices (Fig. 2).

Descriptive statistics in Tab. 1 include the first four moments, the Jarque-Bera test of normality, the Ljung-Box test of level and squared residuals and the DF-GLS unit root test. Brent has high kurtosis, which implies the presence of extreme risk, but all other indices also have high kurtosis, which means that high risk is a common phenomenon in the observed period, particularly due to the pandemic. Autocorrelation is present in all assets except Brent and WIG, whereas all the time series report time-varying variance. These features of the time series can be resolved by some form of the AR-GARCH model. Besides, all the time series are stationary, as the DF-GLS test indicates, which is necessary for the GARCH modelling.

Tab. 1: Descriptive statistics of the selected assets

	Mean	Std. dev.	Skewness	Kurtosis	JB	LB(Q)	LB(Q^2)	DF-GLS
Brent	0.011	1.177	−1.562	26.170	38,310.0	0.241	0.000	−8.758
WIG	0.008	0.546	−1.248	17.372	14,654.9	0.155	0.000	−6.374
PX	0.010	0.419	−1.064	15.414	10,946.7	0.000	0.000	−7.403
BUX	0.015	0.574	−1.383	15.700	11,621.9	0.000	0.000	−20.909
SAX	0.000	0.418	−0.403	14.509	8,923.4	0.001	0.000	−44.632
OMXV	0.014	0.292	−3.096	56.475	198,993.5	0.000	0.000	−16.888
OMXR	0.017	0.504	−0.777	41.551	102,095.1	0.000	0.000	−15.721
OMXT	0.014	0.363	−2.460	34.828	71,785.7	0.000	0.000	−35.429
SOBITOP	0.014	0.372	−1.785	22.859	27,887.3	0.000	0.000	−5.765
BET	0.016	0.458	−1.709	24.696	33,185.9	0.000	0.000	−10.056
SOFIX	0.005	0.346	−2.451	35.449	73,144.7	0.000	0.000	−11.661
CROBEX	0.005	0.345	−3.468	48.391	144,426.2	0.000	0.000	−2.772

Notes: JB – Jarque-Bera coefficients of normality; LB(Q) and LB(Q^2) tests denote *p*-values of the Ljung-Box Q-statistics of the level and squared residuals for 10 lags; 1% and 5% critical values for DF-GLS test with 5 lags are −2.566 and −1.941, respectively.

Source: own

Tab. 2: Long memory tests

	Absolute returns			Squared returns		
	Lo's R/S	GPH	GSP	Lo's R/S	GPH	GSP
Brent	3.864***	0.246***	0.257***	2.737***	0.178***	0.161***
WIG	4.400***	0.234***	0.235***	2.601***	0.161***	0.165***
PX	4.911***	0.305***	0.273***	3.248***	0.344***	0.290***
BUX	4.074***	0.295***	0.268***	2.766***	0.222***	0.209***
SAX	2.591***	0.105***	0.153***	1.660***	0.071***	0.070***
OMXV	3.301***	0.285***	0.271***	1.812*	0.210***	0.200***
OMXR	1.653	0.335***	0.302***	1.246	0.246***	0.240***
OMXT	4.864***	0.370***	0.314***	2.847***	0.381***	0.289***
SOBITOP	3.383***	0.359***	0.312***	2.481***	0.230***	0.215***
BET	2.531***	0.257***	0.241***	2.262***	0.195***	0.162***
SOFIX	3.274***	0.261***	0.249***	1.911**	0.148***	0.138***
CROBEX	2.601***	0.384***	0.322***	2.076***	0.285***	0.231***

Note: *** significance at 1% level, ** significance at 5% level; the critical values Lo's R/S statistics test are 90%: [0.861, 1.747], 95%: [0.809, 1.862] and 99%: [0.721, 2.098].

Source: own

Besides standard descriptive statistics, Tab. 2 tests the long memory property of the unconditional returns and unconditional volatility. Following Youssef (2015) and Alkathery et al. (2022), three tests are performed on absolute and squared returns. These tests are modified R/S statistics of Lo (1991), and two semiparametric estimates of Hurst coefficient, which are the long periodogram (GPH) estimate of Geweke and Poter-Hudak (1983) and Gaussian semiparametric (GSP) estimate of Robinson (1995). Tab. 2 clearly indicates that both GPH and GSP tests verify the presence of long memory for all assets in absolute and squared returns at very high probability. The same applies for the Lo's R/S test, except for the case of OMXR. This means that the use of the FIAPARCH model is justified.

Tab. 3 shows the estimated parameters of the FIAPARCH model of all assets, and also the Ljung-Box Q-statistics of level and squared residuals. The FIAPARCH model fits well for all time series, except for the Slovakian SAX index, where symmetric FIGARCH is used instead. In all cases, δ parameter is highly statistically significant, which means that all assets display strong evidence of volatility asymmetry.

In the seven out of twelve cases, γ parameter is positive and significant, suggesting

Tab. 3: Estimated FIAPARCH models of the selected assets

	Brent	POL	CZE	HUN	SLK	LIT	LAT	EST	SLO	ROM	BUL	CRO
Panel A: Variance equation												
α	0.248**	0.186	−0.152	0.152**	0.618***	−0.467	−0.216	0.315	0.137	0.138	−0.109	−0.001
β	0.476***	0.316***	−0.034	0.360***	0.189	−0.409	−0.181	0.281	0.165	0.311***	−0.046	0.086
γ	0.472*	0.997***	0.518***	0.437***	NA	−0.018	0.244**	−0.026	0.192***	0.390***	0.080	0.075
δ	1.532***	1.443***	1.692***	1.669***	NA	1.637***	1.767***	1.955***	1.689***	1.554***	1.572***	1.651***
d	0.309***	0.188***	0.214***	0.296***	0.371***	0.320***	0.252***	0.326***	0.264***	0.297***	0.234***	0.303***
v	4.509***	8.034***	5.931***	9.991***	2.139***	4.089***	3.243***	4.150***	4.792***	4.836***	4.357***	3.881***
Panel B: Diagnostic tests												
LB(Q)	0.272	0.247	0.529	0.783	0.369	0.329	0.212	0.402	0.377	0.171	0.535	0.222
LB(Q^2)	0.220	0.293	0.652	0.316	0.428	0.476	0.994	0.511	0.118	0.960	0.579	0.998

Note: ***, **, * indicate significance at 1, 5 and 10% level, respectively; LB(Q) and LB(Q^2) tests denote *p*-values of the Ljung-Box Q-statistics of the level and squared residuals for 10 lags.

Source: own

that negative shocks affect volatility more than positive shocks, which is strong evidence that the leverage effect exists in the stock markets. In addition, all *d* parameters are highly statistically significant, which means that the long memory GARCH model can capture the long-range memory phenomenon. All *v* parameters are significant at 99% probability, indicating that Student *t* distribution recognizes fat-tail properties of the time series very well. The Ljung-Box test results suggest that the residuals are free of autocorrelation and heteroscedasticity issues and are therefore suitable for the dynamic CVaR calculation.

Fig. 2 presents the log returns of the selected assets and the two dynamic VaR and CVaR risks, calculated at 95% probability. Fig. 2 clearly shows that extreme risk is present in the observed sample, which is especially evident in early 2020 when the pandemic erupted and in early 2022 when the war in Ukraine started.

The paper tries to estimate the multiscale spillover effect in different time horizons. In this regard, every dynamic downside CVaR time series is transformed into three wavelet scales: scale 1 (2–4 days), scale 5 (32–64 days), and scale 6 (64–128 days). We considered only these three scales in order to avoid results overload.

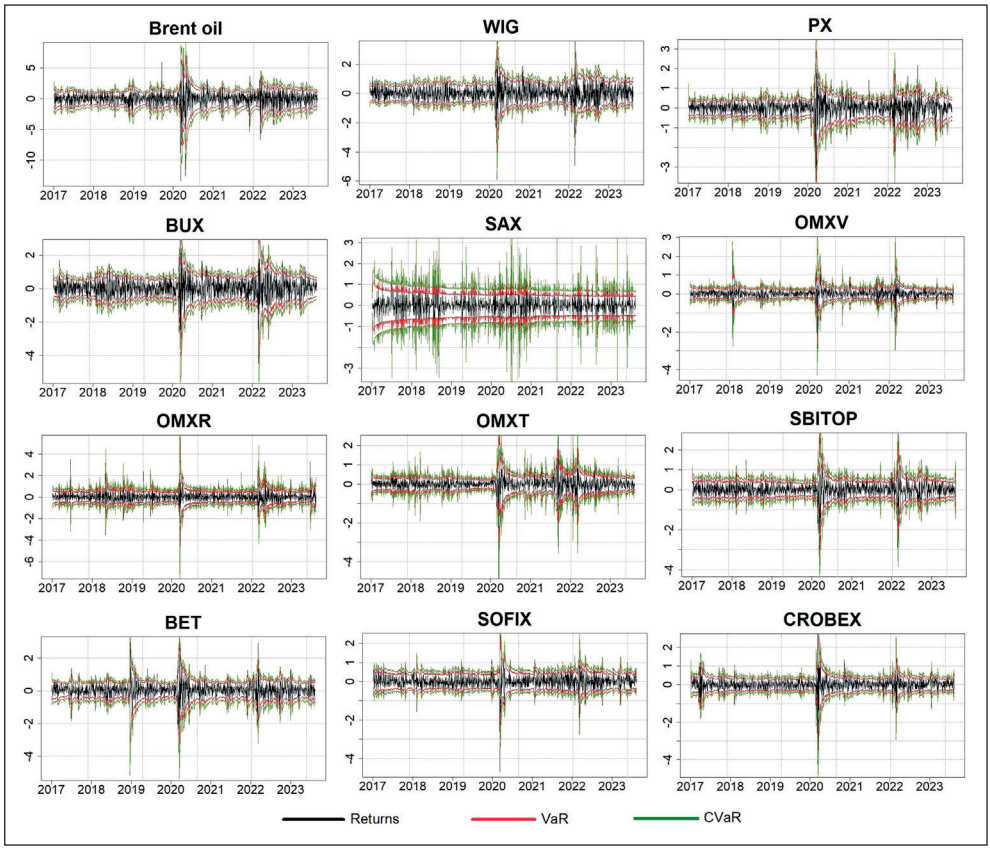

Fig. 2: **Calculated extreme downside and upside risk time series of the stock indices and Brent**

Source: own

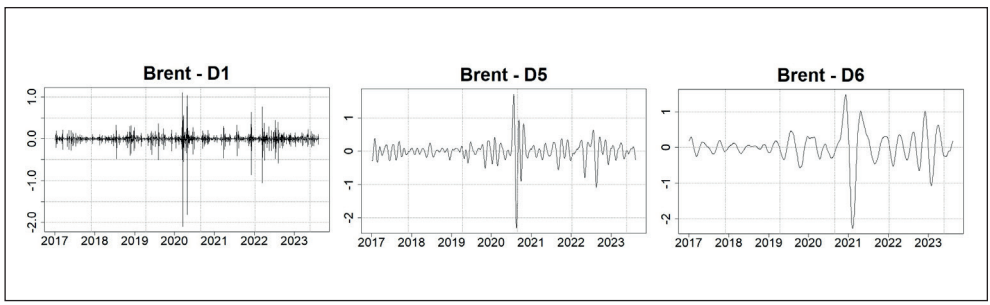

Fig. 3: **Three wavelet details of Brent oil**

Source: own

The first scale corresponds to the short-term horizon, whereas the fifth and sixth scales are regarded as mid-term and long-term, respectively. Fig. 3 shows three transformed wavelet time series of Brent oil using the MODWT methodology.

3. Results and discussion

3.1 Results

This section presents the results of the estimated wavelet-based two-state Markov switching model. State 1 (2) refers to the crisis (tranquil) period, respectively. Tab. 4 shows the results of regime-dependent ϕ parameters, transition probabilities, average expected duration of each regime and regime-specific error variances. All these values are calculated in respect to the three wavelet details. It can be seen that the regime parameters are different across the regimes, wavelet scales and countries, which justifies the use of the wavelet-based MS model.

Most of the regime-dependent parameters are highly statistically significant, which means that the extreme risk spillover phenomenon exists from Brent oil to stock markets in CEECs. On the other hand, the statistically significant parameters are positive and in line with logic in most cases, which suggests that when extreme risk rises in the oil market, the rise of risk in stock markets follows. Only in a few cases, we find statistically significant negative parameters, which means that rising risk in the oil market actually decreases extreme risk in the stock market. However, these parameters are very low, indicating that this counterintuitive phenomenon is very weak and almost non-existent.

Observing Panel A in Tab. 4, which portrays the short-term horizon, it can be seen that relatively strong spillover effect exists in both crisis and tranquil regimes. It is interesting to note that almost always, one regime parameter is significantly higher than the other, suggesting that the spillover effect happens dominantly in one regime. In particular, relatively high statistically significant parameters are found in Czechia, Hungary and Romania in the crisis regime,

Tab. 4: Estimated wavelet-based Markov switching models – Part 1

	POL	CZE	HUN	SLK	LIT	LAT	EST	SLO	ROM	BUL	CRO
Panel A: D1 wavelet scale											
ϕ_1	0.003	0.114***	0.195***	−0.009	0.091	−0.037	−0.010	0.018***	0.309***	0.008	0.042***
ϕ_2	0.170***	−0.002	0.000	−0.280	−0.004	0.024***	0.324***	0.436***	−0.004	0.273***	0.484***
P_{11}	0.920	0.840	0.710	0.900	0.750	0.760	0.930	0.930	0.850	0.930	0.960
P_{22}	0.750	0.920	0.920	0.790	0.970	0.950	0.770	0.700	0.800	0.730	0.720
ED_1	12.300	6.300	3.500	9.700	4.000	4.100	15.000	14.100	1.200	15.100	23.800
ED_2	4.000	12.200	11.900	4.800	32.000	18.50	4.400	3.300	5.000	3.700	3.600
σ_1^2	−3.980***	−2.410***	−2.110***	−3.030***	−1.530***	−1.280***	−3.360***	−3.570***	−1.790***	−3.980***	−3.840***
σ_2^2	−2.410***	−4.220***	−3.800***	−0.980***	−3.860***	−3.150***	−1.480***	−1.740***	−3.780***	−2.350***	−1.840***
Panel B: D5 wavelet scale											
ϕ_1	0.163***	0.370***	−0.002	−0.076***	0.256***	0.296***	0.323***	0.313***	0.114***	0.250***	0.330***
ϕ_2	0.351***	0.091***	0.500***	0.018	−0.005	0.059***	0.094***	0.012**	0.449***	−0.027***	0.014***
P_{11}	0.980	0.940	0.980	0.970	0.950	0.950	0.940	0.950	0.760	0.950	0.950
P_{22}	0.930	0.980	0.950	0.960	0.980	0.990	0.980	0.980	0.240	0.970	0.980
ED_1	48.400	17.700	41.100	36.300	20.300	21.800	16.300	20.600	4.200	20.100	20.800
ED_2	15.100	41.000	19.600	26.800	50.800	74.100	41.400	62.800	1.300	31.000	66.200
σ_1^2	−2.960***	−1.520***	−3.070***	−3.510***	−1.920***	−1.120***	−1.600***	−1.750	−2.720***	−2.380***	−1.600***
σ_2^2	−1.530***	−3.180***	−1.340***	−2.060***	−3.890***	−2.970***	−3.290***	−3.570	−1.370***	−4.100***	−3.510***

Tab. 4: Estimated wavelet-based Markov switching models – Part 2

	POL	CZE	HUN	SLK	LIT	LAT	EST	SLO	ROM	BUL	CRO
Panel C: D6 wavelet scale											
ϕ_1	0.064***	0.037***	0.438***	−0.003**	0.201***	−0.065***	0.263***	0.259***	0.371***	0.196***	0.013***
ϕ_2	0.301***	0.379***	0.045***	−0.016	0.003	0.315***	0.051***	0.027	0.107***	−0.020***	0.307***
P_{11}	0.970	0.980	0.970	0.970	0.970	0.980	0.980	0.980	0.390	0.980	0.980
P_{22}	0.970	0.970	0.980	0.960	0.990	0.970	0.990	0.990	0.600	0.980	0.970
ED_1	35.500	72.600	29.800	37.600	38.200	55.400	42.100	40.600	1.700	44.300	64.200
ED_2	31.000	34.500	44.400	25.900	66.800	36.900	78.600	73.700	2.500	49.400	37.500
σ_1^2	−3.520***	−3.250***	−1.730***	−3.750***	−1.970***	−3.160***	−1.520***	−1.810***	−1.600***	−2.770***	−3.750***
σ_2^2	−1.850***	−1.840***	−3.290***	−2.310***	−3.730***	−1.910***	−3.710***	−3.630***	−2.750***	−4.180***	−1.900***

Note: ***, **, * indicate significance at 1, 5 and 10% level, respectively; the regime-specific error-variances are shown in quadratic form, so they should be observed in absolute values.

Source: own

while five countries endure stronger extreme risk spillover effects when stock markets are in the calm regime (Poland, Estonia, Slovenia, Bulgaria and Croatia). In three countries (Slovakia, Lithuania and Latvia), the parameters are either insignificant or very low. In order to find a rational explanation for the results in Tab. 4, some peculiarities of the countries and stock markets need to be addressed. In other words, it is important to know the level of oil consumption per country, and also the number of stocks in the selected indices. The latter factor is relevant because not all companies listed in some indexes react equally to oil shocks, meaning that the greater the number of shares in the index, the greater the effect of dispersion, that is, the lower the impact of oil shocks on the index. In this regard, Tab. 5 contains oil consumption per capita and the number of stocks in the indices.

Czechia, Hungary and Romania endure the strongest spillover effect from oil in the crisis regime in the short term, 0.114, 0.195 and 0.309, respectively. At first glance, these results seem perplexing because Romania has the lowest oil consumption per capita (Tab. 5), but suffers the greatest impact from oil shocks. However, Romania is the largest oil producer in Central and Eastern Europe, according to CIA World Factbook data from 2020, with a production of 70.000 bbl per day. This means that the Romanian energy industry is an important contributor to the Romanian economy in terms of manufacturing, tax revenues, and export. Besides, several Romanian energy companies are listed in the BET index, which could be the reason why BET suffers the highest impact from the oil market in the crisis regime in the short term. On the other hand, for the Czech and Hungarian cases, the reasons are different. These stock exchanges, and particularly Hungarian, are among the most developed stock exchanges in Central and Eastern Europe, according to Baele et al. (2015), which means that these markets process new information the most effectively. This is especially true in turbulent times, which explains why statistically significant ϕ parameters are found in the first regime. In addition, it should be noted that expected duration of the crisis regime is significantly shorter compared to the calm regime in these countries, which is particularly true for the more developed Hungarian market. This signals that investors in these markets react promptly at any sign of negative information shocks in order to avoid further losses. These results coincide with Marek and Benada (2020), who investigated the Prague Stock Exchange. The Polish stock exchange is also in the group of the developed markets in CEECs, according to Baele et al. (2015), but ϕ parameter in the first regime is insignificant, which means that extreme oil shocks do not affect WIG in crisis, but rather in tranquil period. The rationale

Tab. 5: Oil consumption per capita and number of stocks in the indices

	POL	CZE	HUN	SLK	LIT	LAT	EST	SLO	ROM	BUL	CRO
Bbl/day per 1,000 people[a]	14.69	19.23	14.72	15.29	19.00	13.63	24.32	15.29	8.97	12.93	15.29
Number of stocks in index[b]	296	10	17	1	10	9	9	8	17	15	11

Note: Bbl – barrel of crude oil.

Source: own (based on [a] CIA World Factbook – information is accurate as of January 1, 2020 (Central Intelligence Agency, 2020); [b] https://www.investing.com, accessed on August 2023; www.nasdaqomxnordic.com is used for OMXV, OMXR and OMXT indices)

could lie in the fact that the Polish stock market is the biggest, with significantly more quoted companies than in any other country from Central and Eastern Europe (Tab. 5). This suggests that the effect of dispersion is more present in the Polish stock market than in any other CEEC.

In the cases of smaller and less developed markets, such as Estonia, Slovenia, Bulgaria and Croatia, we find relatively high parameters in the second regime. Estonia has the highest oil consumption per capita, while all other countries have relatively high oil consumption (Tab. 5). However, all these markets are relatively underdeveloped and illiquid, which means that the fast reaction of market participants to external shocks is not happening. This is probably the reason why extreme risk spillover is detected in the second regime. Slovakia, Lithuania and Latvia also belong to the group of less-developed markets, while the Slovakian stock market is particularly illiquid. In these cases, statistically significant ϕ parameters are not detected. In the Slovakian case, SAX lists only one company, Biotika, which is a pharmaceutical company that is by default less susceptible to oil shocks. This fact explains a lot of why statistically insignificant parameters are found in the Slovakian case.

Our results are generally in line with Salisu and Gupta (2021) and Gupta et al. (2021). The former paper researched the response of stock market volatility of the BRICS countries to oil shocks and found heterogeneous results. They asserted that differences in the economic size, financial system, oil production (consumption) profile of the countries and regulation efficiency can explain these divergences. The latter paper analysed the impact of different factors such as: global economic activity, oil supply, oil-specific consumption demand, and oil-inventory demand shocks on the tail risk of equity markets in the panel of 48 emerging and developed economies. They asserted that oil-specific consumption-demand shocks are associated with an increase in tail risks.

Looking at additional findings, Tab. 4 shows that all regime-dependent probabilities are relatively high, which refers to the likelihood of being in a particular state at a given point in time. This indicates the probability that the observed data at a specific time period were generated by a particular regime. Besides, all sigma parameters are highly significant, which means that a certain magnitude of volatility is present in each regime.

On the other hand, Panels B and C show results in midterm and long term, revealing different findings compared to the short-term horizon. In the first place, some countries, such as Lithuania and Latvia, report spillover effect in the longer time horizons, whereas this is not the case in the short term. Besides, the spillover effect intensity is generally higher in longer terms, which is especially the case for countries which have high spillover effect in the crisis regime, such as Czechia, Hungary and Romania. In particular, Czechia has significant ϕ parameters in midterm and long term in amounts of 0.370 and 0.379, respectively. Hungarian parameters are 0.500 and 0.438, while for the case of Romania, they are 0.449 and 0.371, respectively. Our findings of higher risk spillover effect in the longer time horizons is similar to Mensi et al. (2022b), who researched the extreme risk spillover effect from oil to ASEAN stock markets, using the CVaR measure of risk. They claimed that these results

suggest that long-term spillovers persist more than short-term spillovers. The paper of Li and Wei (2018), also finds a higher oil spillover effect in the long term, researching the case of China. They explained that this may indicate that market participants are paying more attention to long-term volatility in the crude oil market when creating their trading strategies. It is interesting to note that Slovakia is the only country where the spillover effect is not found in the mid-term and long-term horizons, whatsoever, which strongly indicates that Slovakian stock market is highly inefficient and illiquid. This means that the Slovakian stock market is not capable to record shocks from the oil market in any time horizon.

3.2 Discussion

The results can have significant implications for investors in the CEE stock markets, portfolio managers and policymakers. The investors in stock markets should take into account the magnitude of the spillover effect during a crisis and tranquil conditions regarding different time horizons, in order to properly manage external oil shocks, which coincides with the paper of Jiang et al. (2022). In other words, knowing the size of the risk spillover effect, market participants could formulate workable hedging strategies that will mitigate the impact of oil markets. Also, in every stock exchange, different market participants operate in different time horizons. Therefore, having information about the size of the spillover effect in different time periods can indicate what type of hedging instruments market agents should apply in order to reduce extreme risk shocks from the oil market. In some instances, such as the Slovakian case, no hedging strategies are needed in any time horizon because the Slovakian stock market does not absorb oil shocks due to high illiquidity. Based on the results, investors in stock markets can decide whether and when to take short- or long-term positions in particular indices. The aforementioned is in line with the conclusions reached by Gupta et al. (2021), who asserted that investors must be aware that the nature of oil-market shocks matters in driving tail risks, and, hence, the corresponding impact on the equity premium is shock-dependent. They researched the effect of tail risk as we did, but with a different methodology and on a different sample. Our improvement compared to the paper of Gupta et al. (2021) is reflected in the fact that we add the wavelet methodology to distinguish between different time horizons.

Besides, the results have implications for portfolio managers or investors who want to pair oil with CEEC stock indices in the same portfolio. In other words, if a particular index endures a heavy risk spillover effect from the oil market, this is a strong indication that these two assets should not be combined in the same portfolio. For instance, it is not a good decision to combine the Romanian BET index with oil, when the stock market is in turbulent mode in the short time horizon. The same applies to the Estonian, Slovenian and Croatian index in tranquil times in the short term. On the other hand, when a less sensitive index to spillovers dominates the portfolio, diversification may be more effective. Being aware of the presence of risk spillovers requires thoughtful placement and careful rebalancing of the oil stock portfolio. This takes careful thinking about the perspective of different investment horizons because it is obvious that long-term stock investments are more exposed to extreme oil risk shocks than short-term investments. This is in line with the assertion of Tian et al. (2022), who state that fund managers and global investors should evaluate comprehensively the risk measurement of risk contagions and accordingly adjust their positions to optimize their portfolio strategies.

At the end, the results also have important message for policymakers and their macroprudential regulation measures. In other words, in those countries that are very susceptible to extreme risk shocks from the oil market, policymakers may need to implement and enforce stricter regulations to limit the risk transmission between oil and stock markets. These regulations could include requirements directed at financial institutions exposed to oil shocks or placing limits on their holdings of oil-related assets. In addition, regular stress testing of financial institutions to assess their vulnerability to oil price shocks can help identify potential weaknesses in the financial system and guide appropriate policy responses. Based on the different time horizons in which shock spillovers occur, it would be very useful if policymakers could implement targeted reforms that reduce the vulnerability of stock markets in different time horizons. Such reforms could help regulators to control systemic spillover effects while at the same time minimizing the fear effect

arising from investor behavior during downturn market scenarios.

Conclusions

This paper investigates the extreme risk transmission from oil to eleven emerging stock markets of Central and Eastern Europe. In this process, the scale-dependent non-linear relationship is analysed. First, the dynamic CVaR time series are estimated by the long memory FIAPARCH model. Then, three decomposed wavelet details are created by the MODWT methodology, which reflects different time horizons. In the final step, the wavelet time series are embedded in the two-state Markov switching model that reveals non-linear dependence between the markets.

According to the results, most of the regime-dependent parameters are highly statistically significant, confirming that extreme risk spillover effect exists in the CEECs. The regime-dependent parameters are always significantly higher in one regime, which means that the spillover effect dominantly happens in one regime. Results are heterogeneous among the countries, which indicates that certain idiosyncratic characteristics of the countries are responsible for such findings. Relatively high statistically significant parameters are found in the cases of relatively developed Polish, Czech and Hungarian stock markets. On the other hand, the Romanian market does not belong to developed stock markets, but it is the largest oil producer in Central and Eastern Europe, whereas several Romanian energy companies are quoted on the Romanian stock exchange. This could be the reason why BET suffers the highest impact from the oil market in the crisis regime in the short term.

In the case of relatively small and inefficient stock markets, such as Estonia, Slovenia, Bulgaria and Croatia, the results indicate a relatively high spillover effect in the tranquil regime. All these countries have high oil consumption per capita, which might explain high spillover effect in the second regime. Slovakia, Lithuania and Latvia do not report the spillover effect whatsoever in the short term, probably because they are inefficient and illiquid. An interesting finding is that the spillover effect is stronger in longer time horizons, which suggests that the long-term spillover effect is more persistent than the short-term counterpart, and also, this could mean that market participants are more cautious about the long-term volatility in the crude oil market when making their trading strategies.

Based on the results, stock investors could formulate viable hedging strategies that will reduce the impact of oil markets. Portfolio managers could also benefit from the results, particularly those that combine oil and stocks in a portfolio. The policymakers could use the results to decide whether particular measures have to be implemented in order to reduce the vulnerability of stock markets in different time horizons.

This paper researches emerging East European countries, but future studies can use the same methodological approach, focusing on other emerging markets around the globe, e.g., the region of South East Asia, Central Asia, North Africa, Pacific-basin countries and countries of Latin America.

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The impact of chatbots on the buying behaviors of Generation Z toward brands

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Abstract: *As society develops, so do the needs and wishes of customers, the market situation, and especially the competition. The procedures and essential tools of traditional marketing that worked before are gradually losing their effectiveness and are no longer able to ensure a competitive advantage. If businesses want to have a competitive advantage, they must be prepared for these changes and be able to respond to them appropriately. There is currently a generational change in household spending; thus, the customer's preferences have changed significantly. If a brand wants to remain relevant in the future market, which will be shaped by the new generation of customers, it is appropriate to focus on the Generation Z customer segment. Generation Z is the youngest generation targeted within marketing strategies and at the same time the generation with a lot of changes in product/service perception. Generation Z will be the biggest future challenge for marketing. This paper is dedicated to Generation Z in the market of the Czech Republic. Providing insights from in-depth interviews with Generation Z individuals, this research reveals their expectations, behaviors, and preferences when engaging with brands' chatbots. The findings shed light on essential factors that influence customer satisfaction and loyalty, such as the availability of human agent transfer, clear robot interaction differentiation, and seamless problem-resolution processes. The paper aims to identify the preferences of Generation Z brands' interaction via chatbots. The paper will, therefore, provide an understanding of how a brand can build strong relationships with Generation Z customers through an innovative marketing approach that uses chatbots to communicate with customers 24/7/365.*

Keywords: *Brand, communication, customer service tool, chatbot, AI, innovation, innovative marketing.*

JEL Classification: *M30, M31, O39.*

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Introduction

In a digital era where customer engagement is pivotal for brand success, innovative marketing approaches play a crucial role in shaping consumer-brand interactions. This article delves into the realm of utilizing chatbots as a strategic tool to foster relationships between brands and Generation Z customers. Chatbots, defined by Microsoft as software applications engaging with users in natural, human-like conversations, offer a novel avenue for brands to connect and communicate with their target audience effectively (Microsoft, 2023).

Chatbots are used for a variety of purposes in a wide range of industries to help interact with web services or applications using different text, graphics, or speech. They can understand natural human language, mimic interaction, and perform simple, automated tasks. Their use can be found at various levels, such as in messaging applications, mobile applications, websites, telephone lines, or voice applications (Malik et al., 2021). Chatbots are considered to be an important tool for increasing the efficiency of customer service (Hsu & Lin, 2023). The benefits are mainly found in providing continuous customer service (Følstad et al., 2018). Currently, websites, e-shops, or mobile applications are where they are most widely implemented. While chatbots can take many forms, they are most often used as human agents to respond to customer needs and issues (Sheehan et al., 2020). Since the COVID-19 pandemic, the use of chatbots and retail spending via bots has increased significantly in all business areas (Melovic, 2022).

The paper sheds light on how Generation Z perceives the current marketing strategy of brands in the form of using chatbots. This research recognizes Gen Z's affinity for technological innovation and, using qualitative interviews, examines Gen Z's preferences for the use of chatbots by brands. With Generation Z poised to be a significant driving force in future consumer spending, understanding their preferences and interactions with brands through chatbots becomes imperative for marketing practitioners.

By addressing gaps in existing literature surrounding chatbot-customer interactions, particularly within the context of Generation Z, this article aims to provide insights into the evolving landscape of customer-brand engagement. These findings are poised to offer valuable implications for practitioners and researchers, especially in unearthing insights pertinent to the Czech Republic market. The exploratory research methodology will be employed to attain the findings. A qualitative research approach will be adopted, with in-depth interviews selected as the primary method. A non-probability purposive sample technique will be utilized to select participants within the age range of 20–27 years. The data will be analyzed using thematic analysis as the chosen method. The paper aims to identify the preferences of Generation Z brands' chatbot interaction. The focus is on the new innovative customer service tool in customer-brand interactions that has already proven to have the potential to meet the current and future needs of Generation Z. In addition to the exploration of customer perceptions of current use of brands' chatbots, this empirical paper is focused on the following key research questions (*RQ*):

RQ1: What will the future of customer – brand chatbot interactions be?

RQ2: What are the expectations of Generation Z customers toward brands' chatbots?

The findings will be important for practitioners and new researchers because experiences related to the research problem are still modest, especially in the Czech Republic.

1. Theoretical background

1.1 Brand communication

In the realm of customer-brand relationships, effective brand communication stands out as a crucial factor that can either strengthen or jeopardize the bond between a brand and its customers. Building and maintaining strong relationships with customers is essential for long-term success and sustainability in today's competitive marketplace (Zulfikar et al., 2022). Positive brand communication plays a pivotal role in fostering relationships and cultivating brand loyalty. Transparent and consistent communication helps convey the brand's values, identity, and commitments to customers, building trust and credibility over time (Yang & Battocchio, 2020). By engaging in meaningful dialogue, actively listening to customer feedback, and offering personalized experiences, brands can create emotional connections with their audience, leading to increased customer loyalty and advocacy (Magids et al., 2015).

However, amidst the benefits of brand communication, there exist risks that can potentially drive customers away from a brand. Poor communication practices, such as unclear messaging, inconsistent branding, or lack of responsiveness to customer inquiries, can erode trust and damage the brand-customer relationship (Cleave et al., 2016). Miscommunications, misaligned brand messaging, or insensitive responses to customer concerns can alienate customers, leading to dissatisfaction, negative word-of-mouth, and, ultimately, customer defection (Taghizadeh et al., 2013).

In navigating the complexities of brand communication, it is imperative for brands

to prioritize authenticity, transparency, and empathy in their interactions with customers. By actively listening to customer feedback, addressing concerns promptly, and maintaining open channels of communication, brands can mitigate risks, build stronger relationships, and foster lasting loyalty among their customer base. Ultimately, the art of brand communication lies in creating meaningful connections that resonate with customers, fostering trust, loyalty, and advocacy that transcend transactional exchanges (Kemp et al., 2021; Sheninger & Rubin, 2017; Yang & Battocchio, 2020).

Although a chatbot still cannot fully replace a person in interaction with a customer, it is undoubtedly an important tool for brands in communication and building a relationship with the customer (Li & Zhang, 2023). By integrating chatbots into the marketing strategy, brands can grow their digital presence, establish themselves on the market as a separate, unique entity, and even reap the benefits of opening up new potential revenue streams (Rydiger, 2023).

1.2 Chatbots and customer interaction

Currently, there are two categories of chatbots: ones that operate according to a set of rules, and ones that use artificial intelligence. The first category, rule-based chatbots, will only be able to understand a limited number of options that have been programmed into the chatbot. It operates by predefined rules. Rules-based chatbots are easier to build because they use a set of simple true/false algorithms to comprehend user requests and respond appropriately (Hingrajia, 2023). The second case is the utilization of artificial intelligence (AI) in AI-powered chatbots. It can understand open-ended queries because it is engineered with machine learning algorithms. Not only does it have an understanding of queries, but it also comprehends language. Since the chatbot learns from its interactions with users, it is always improving. AI identifies language, context, and intent and reacts appropriately (Song & Shin 2022).

Technology that acts, reacts, or behaves intelligently and can manifest in anthropomorphic and non-humanoid forms is referred to as artificial intelligence (AI). Through learning, analyzing, and interpreting data, they mimic or perform human tasks and help solve problems. Artificial intelligence has rapidly evolved from simple task performance (e.g., Siri) to more sophisticated social functions such as customer emotion recognition for subsequent intervention. Artificial intelligence can be effectively used in reasoning, explanation, modeling, and prediction (Rizomyliotis et al., 2022).

The relationship between businesses and their customers is being revolutionized by the use of robots as multi-tasking customer service agents. AI chatbots are increasingly being used on the front line to help engage customers. The use of chatbots for the first interaction can assist in the identification of customer needs and wants (Prentice et al., 2020). Based on data collection, chatbots can identify customer needs and issues and escalate them to humans when appropriate. Chatbots provide a positive and consistent level of interaction, promote seamless service, and influence customer preferences (Huang & Rust, 2018).

Providing quick answers to usually simple customer service questions is the primary expectation customers have of chatbots (van der Goot et al., 2021). However, expectations may vary depending on the type of chatbot. If the chatbot is anthropomorphic, i.e., given a name and its behavior is close to that of a human, the customer will behave differently in the interaction (Xu et al., 2022). A humanized agent is able to plan, act, and react similarly to a human, which means that expectations are heightened. These higher expectations increase customers' hopes that the chatbot will be able to help them. While non-humanized chatbots often negatively impact users by being perceived as cold, impersonal, and unfriendly, an avatar chatbot, on the other hand, significantly contributes to user satisfaction and positive reviews. Interaction with an anthropomorphic chatbot results in higher levels of trust and, therefore, easier persuasion of users. At the same time, chatbots are held more accountable for their actions. In the event of disappointment, customer dissatisfaction is quickly exacerbated (Song & Shin, 2022).

Another important aspect of customer satisfaction with the chatbot interaction is the customer's mood. So, how do angry customers react to chatbots, and is it beneficial to humanize the chatbot in this case? An Oxford University study analyzed over 1.5 million text records of customer interactions with a customer service chatbot. Humanizing the chatbot improved customer satisfaction, except when customers were angry, according to the analysis. For those customers who

entered the interaction in an angry emotional state, the anthropomorphism had a drastically negative effect on their final level of satisfaction (Hadi, 2019).

In conclusion, it is important to emphasize when the use of anthropomorphic chatbots is appropriate and when it is not. In the Oxford study, anger played an absolutely central role. Therefore, it is crucial to determine the customer's state of mind. One way to do this would be to use keywords. Disgruntled customers could then be redirected to the non-humanized chatbot, while others would stay with the anthropomorphic version. Another option is to immediately divert angry customers to human agents, who may have greater empathy and be more likely to resolve the issue to the customer's satisfaction (Crolic et al., 2022). For this reason, humanized chatbots are not the right choice for complaint centers and can dissuade customers, even though they have undeniable advantages over their non-human counterparts.

With the development of technology, chatbots have more and more power to influence customer perception of brands. For customers, interaction with a chatbot can be a useful and entertaining way of communication that consolidates and improves the brand image. If a company is looking for a way to promote a brand, a chatbot becomes a useful tool to change communication and customer perception. Chatbots help create brand awareness and especially a unique experience that customers remember. A good example is the Indian bank HFDC, which created a visual mascot to help with customer support. The avatar was so distinctive and memorable that it began to spread virally among people and co-created the bank's brand. Thus, the nature of the chatbot and the personalized approach that deepens the trust and impression of customers is important in building a brand (Makadia, 2022).

It is obvious that the customer always comes first. That means that customer behavior needs to be analyzed in detail (Maráková et al., 2023). Such are customer perception, needs, preferences, things that influence them, principles of loyalty, and everything that influences the customer decision-making process (Stefko et al., 2023). Also, the procedures and basic tools of traditional marketing that worked before are gradually losing their effectiveness and are no longer able to ensure a competitive advantage.

If businesses want to have a competitive advantage, they must be prepared for these changes and be able to respond to them appropriately. Based on an IBM report, Generation Z will account for nearly a third of all global revenue within six years (IBM, 2017). It is evident that there is currently a generational shift in household spending and thus, a significant change in consumer preferences. If a company wants to remain relevant in the future market, which will be shaped by the new generation of customers, it is appropriate to focus on the Generation Z customer segment. For that particular reason, the next section is dedicated to the youngest generation targeted within marketing strategies, Generation Z.

1.3 Generation Z

Individuals that are born about the same time or during a specific period possibly experience the same significant events (i.e., same political, economic, and social events such as technological developments and financial instability) and will develop a similar set of beliefs, values, and behavior. Generational cohort theory proposes that it is possible to predict customer responses based on the year they were born. That is why it is possible to adjust innovative marketing strategies to specific customer cohorts.

The current focus of marketing is on four main generations: Baby Boomers, Generation X (Gen X), Generation Y (Millennials), and Generation Z (Gen Z). Each generation holds beliefs and preferences that shape their thinking and actions. Research has already shown that if a product is preferred by a Generation Z customer, it will automatically increase in popularity with Generation X customers. Thus, if marketing strategies target Generation Z, it can be expected to be largely successful for Generation X. In addition, members of Generation Z influence their parents' purchasing decisions (IBM, 2017).

Generation Z is the youngest generation targeted within marketing strategies, and Generation Z's behavior as customers differs, which is why this section provides insight into the current customers' minds and already implemented research of this generation in other countries.

Generation Z is a generation cohort of individuals born between the mid-1990s and early 2000s (Suryadi et al., 2021). This is a period in which Generation Z is being debated by researchers. There is also evidence that

Generation Z includes those born between 1996 and 2012 (Bhore & Tapas, 2023). According to Tapscott, Generation Z began in 1998 (Tolstikova et al., 2023). Generation Z is estimated at more than 2 billion young people. With nearly a third of the global population, it is the most populous generation on the planet (Mude & Undale, 2023).

In terms of diversity, it is considered to be the most diverse generation (Kaplan, 2020). This generation is, in many ways, the most demanding group of customers we know so far (IBM, 2017). They are digitally savvy, the best informed, have the highest expectations, and they are the least loyal customers, or better said their loyalty is based on other principles. The youngest generation is the most value-driven (IBM, 2017).

Generation Z wants brands to reach out to them with immediate answers to their questions tailored to their needs. They expect to receive incentives and offers that are relevant to them personally. Equally important, Generation Z prefers brands that can engage with them in real-time and one-on-one. If a typical Generation Z has feedback or an idea for a brand, there's a good chance they will have more respect for the brand if they can get back to them with a thoughtful response within the next few minutes (Betz, 2019).

The bottom line is that without innovative marketing and technology, many marketing teams cannot keep up with the level of personal brand engagement that Generation Z demands. Online marketing is considered an innovative marketing approach that represents an evolution of offline marketing. Adequate online presence, good social media management, and interaction with the community can help attract potential clients (Daemi et al., 2021). Chatbots are a tool used by companies in online marketing to differentiate themselves from competitors and improve customer service. They have become a tool for companies to better utilize social networks and gain a distinct advantage at the internet level over other companies that do not use them (Araújo & Casais, 2020).

2. Research methodology

2.1 Research design

Given the exploratory nature of this research and the lack of existing research on customer expectations of chatbots in the Czech Republic, a qualitative research design was used (Creswell, 2009). Another reason why qualitative research was used is the aspiration to enable a descriptive analysis of many respondents' answers that reflect the attitudes of their subconscious. The outputs of individual interviews are recorded in terms of characteristics and relevance for the wider population (Anderson, 2010; Farris et al., 2009; Johnson, 2004). At the same time, the ratio in which the interviewees agree is mentioned for the individual answers.

This research approach was undertaken since it provides a better initial understanding of the topic, in-depth exploration of viewpoints, and identification of factors that influence their attitude towards the phenomenon, which contributes to the development of an overall better understanding of the issue (Stokes & Bergin, 2006). In-depth interviews enable the interviewer and the interviewee to be closer and to understand each other better (Bell et al., 2022).

A series of in-depth, semi-structured, face-to-face, one-on-one interviews were conducted with the respondents belonging to the Generation Z cohort. The first phase of the research itself was its preparation. First, the objectives of the in-depth interview and the information to be found were determined. According to the aim of the research and the literature research already carried out, the script itself was written. Apart from the main topics, the script included specific side questions, which helped to get deeper into the problem and helped to make the interviewee feel comfortable so that he would become more open to the conversation.

The purchasing power of Generation Z is on the rise and directly affects the spending of their parents included in Generation X, who currently hold the majority of purchasing power (Fromm, 2022; Wang, 2021). Generation Z is known to be tech-savvy, having grown up connected to technology since birth, and they are the most demanding group of customers we know so far (IBM, 2017). Furthermore, it has already been confirmed by many researchers that younger generations usually adopt innovations more easily and faster than older generations (Damanpour & Schneider, 2006).

Every market is segmented into five customer groups according to Geoffrey Moore's Crossing the Chasm theory: innovators, early adopters, early majority, late majority, and laggards. This segmentation is based on

the premise that offerings to these customer groups are designed to reflect their stage of adopting a given technology. Typically, new offerings are targeted primarily at the innovators because they are more likely to be open to new technologies. A higher proportion of innovators could be expected in the sample which consists of students. They also influence the behavior of other customer groups that subsequently embrace innovation.

Based on research already conducted, it is reasonable to assume that each generation has different impressions of customer service chatbots (Fan et al., 2022). Moreover, when creating campaigns, commercial messages, and content, companies must consider differences in the interest and involvement of Generation Z in different markets. The survey shows that Generation Z customers in growth economies differ in priorities from their counterparts in developed markets (IBM, 2017). Developing countries, so-called emerging economies, have markets with fast-growing economies, such as some nations in Asia, Central Europe, and Latin America. Developed markets are markets with economies that have established a significant degree of equilibrium, such as the United States, Western Europe, and Japan (IBM, 2017). For this reason, the goal of understanding how a company can build strong relationships with customers from the Generation Z cohort through an innovative marketing approach that uses chatbots to communicate with customers is dedicated only to the Czech Generation Z.

2.2 Sample, data collection and analysis

A non-probability purposive sample was used as the participants were selected on the basis of their age (20–27 years). First of all, 48 first-year master's students at the Technical University of Liberec were approached, and 37 (20 female and 17 male) took part. To qualify, participants had to self-report that they had interacted with a chatbot in the past. In August 2023, the interviews took place. The sample size was deemed adequate for the purposes of this paper and for qualitative research more broadly, being large enough to provide useful information about underlying patterns and small enough to allow for effective analyses. It meets the criteria of Onwuegbuzie and Leech (2007), who propose a sample size of between fifteen and twenty people, while de Ruyter and Scholl (1998) suggest that between fifteen and forty respondents is the most common sample size. A semi-structured interview guide was used to collect data. Flexible, open-ended questions were used as a means of stimulating discussion. The interview guide has been developed on the basis of the literature review (Rizomyliotis et al., 2022; Song & Shin, 2022) and has been pre-tested for its relevance to the research questions. The interview questionnaire consisted of 10 questions designed to elicit information from the participants' personal experiences of interacting with chatbots and their expectations of this interaction. Four demographic questions were asked of participants.

The average duration of the qualitative interviews was around 50 minutes. Ethical guidelines were followed during the interviews, including no harm, informed consent, anonymity, and honesty principles (Bell et al., 2022). Respondents were informed that there were no right or wrong answers and that honest and open responses were encouraged. To increase the accuracy of data collection, the interviewer paid more attention to the interviewee and allowed for verbatim transcription. The interviews were audio-recorded with the interviewee's consent. Participants' names were replaced with coded numbers to ensure anonymity. Thematic analysis was used for data analysis. Following the approach described by Ryan and Bernard (2003), the information collected was organized into categories or themes, and the data was categorized for analysis. The differences and similarities were analyzed in more detail by treating each question as a separate category and by analyzing all the responses for each question at the same time. In addition, this method made it possible to compare and contrast information and data from both primary and secondary sources (Saunders et al., 2009).

3. Results

To open the conversation, the participants were asked about their expectations when communicating with businesses (brands) and about their habits when interacting online. Most customers (more than four-fifths) said they were excited about the transition of everyday activities like shopping, studying, meeting new people, dating, and working out to the metaverse.

"I must admit that what I enjoyed the most about COVID-19 was the possibility to work/study online. I did not need to worry about the schedule, as I only had to log in to attend

the meeting/lecture. Honestly, that can be transmitted to other areas as well. I do enjoy shopping online, even for the grocery. It does not take much time and is delivered to the doorstep. There is also the possibility to save the shopping basket content for next time. Then, you can shop for your usuals with a few clicks in minutes. I have learned to be time-efficient by transferring daily activities to the online sphere (Interviewee No. 3)."

When it comes to the speed at which brands communicate with their customers, Generation Z customers are very straightforward and unanimous. Their expectation is for fast communication that does not require a significant effort on their part. When asked about their preferred form of brand communication, they surprisingly favored personal, one-on-one communication with a live human being. The speed of a brand's communication has an impact not only on customers' trust in the brand, but also on their long-term loyalty to the brand.

"Easy form of communication with the brand is very important to me. When I am satisfied with the customer service, I stay loyal (Interviewee No. 5)."

Czech Generation Z customers unanimously agree that brands should value their opinions. When customers of this generation were asked how they perceive that brands value their opinions, they indicated that the main way in which they value their opinions is through the brand's willingness to communicate further with the customer. Almost three-quarters stated that even if they are satisfied with the brand of product they use regularly, they are still very open to exploring and buying identical products from other brands. When asked what would increase their loyalty to those brands they are already satisfied with and use regularly, they said that one of the most important aspects of their brand loyalty is how and when they are contacted, and the speed at which the brand communicates with them.

"I buy food supplements on a regular basis, I also read a lot about the benefits of each combination, but I always tried to look up different brands in different e-shops. But once there was a problem with the packaging of the supplements I bought and I took a photo and I complained to the shop. In a few minutes, I get an apology email and right after that another email with shipping information. They sent me the same product and a small present as an apology. Since that time, I only shop in that brand shop. I must admit that communication with them is better than with my friends. Whenever I have some questions, I contact them via Facebook messenger, and within a few minutes, I always get the recommendations I need (Interviewee No. 32)."

While communicating with brands, participants expect two-way engagement on the devices and channels of their choice. Nearly three-quarters of participants said they either received no response or an unsatisfactory response from the brand they attempted to contact.

"Many times happened to me that I tried to contact the brand or e-shop via social media platforms and I never get any answer. It is frustrating, it should be an interactive platform (Interviewee No. 24)."

Moreover, according to more than nine-tenths of the participants, brands that consistently strive to be better through innovation are more likely to improve customer loyalty and satisfaction among their generation. They recognize companies for their product innovation, as well as their innovative approach to their overall performance at various levels of marketing. When used correctly, chatbots can be the answer to these issues and the right solution for Czech Generation Z expectations. This is an opportunity for brands to win over this generation. If the key aspect of understanding customer preferences is met, chatbots can be a way to make a positive impact on the minds of customers while simultaneously trying to optimize marketing budgets. So how does Czech Generation Z perceive chatbot interaction and what are their preferences?

As stated in the research methodology, all participants were selected to have previous experience using a chatbot in some form. Less than two-thirds of participants are inclined to use a chatbot again in the future.

"When you need a quick answer, chatbots are easy to use and convenient. Then they are a reliable way to communicate without having to wait on hold (Interviewee No. 19)."

One-third of participants were neutral about the issue of repeat interaction with chatbots after previous experience. If there is no other way to contact the company at the time, they will try to interact with a chatbot, but will not primarily seek it out. If other customer service channel options are available, they are used

first. One-tenth of participants deliberately avoid such communication in the future due to bad experiences.

"When I get the choice of contacting a live person or a chatbot, I prefer to call even if I pay for communication with a call center employee, but if I am not connected repeatedly, I start looking for other communication options. However, a chatbot is never the first choice. Especially since I fear an unsatisfactory response and never formulate the command precisely enough for the chatbot to understand me (Interviewee No. 2)."

This ratio significantly changes when participants know at the start of an interaction with a chatbot that they can be easily and quickly transferred to a conversation with a human agent if it fails. The moment they are aware that if they repeatedly submit a query and do not receive a relevant answer, they can be seamlessly transferred to a customer service agent, either via a button in the chat box or an automatic conversation redirect, then they are all inclined to use this service channel.

"If I knew from the start that after the chatbot fails a couple of times, I would be transferred with all the details to a live agent, I will give it a shot (Interviewee No. 37)."

Half of the participants said that being seamlessly transferred to a human customer agent along with relevant information when the interaction failed would impact their willingness to do business with the company in the future.

"Some brands have right from the start the possibility to contact the customer service agent via chatbot and that is something I do appreciate especially if I know my inquiry is complex (Interviewee No. 6)."

When participants were asked about the number of chatbot failures before abandoning the interaction, two-thirds said they would be willing to paraphrase their request up to 2 times, and one-third of research participants were willing to give the chatbot overall 4 attempts. On average, participants showed a high level of forgiveness for chatbot failures, giving it 3 attempts before abandoning the chat completely.

"I enjoy discovering new technologies, and I would mostly choose to communicate with a chatbot at midnight or any other time that is convenient for me. I usually want an answer right away to complete the entire purchase process so I do not have to come back to the exact same order the next day or, even worse, days later when the company replies to my email. That is something incredibly frustrating for me when I cannot decide right away and have to put it off for another time. Frankly, I do not have much of a choice and prefer to try to get information from the chatbot, so I would give it 4 or even more chances depending on the quality of the interaction and how far or close it would get to the requested information (Interviewee No. 25)."

The effect on the likelihood of being a customer of a brand if a problem is not resolved the first time a chatbot is used is enormous. A failed chatbot experience negatively impacts the likelihood of remaining a customer, according to almost half of the participants.

"It depends if it is before or after purchase. If the chatbot fails pre-sale, I mostly just give up. If it is something I want badly, then it depends on whether there are other resellers of the product or other brands. If so, I automatically move on to a different company. Otherwise, I am willing to look up other contact information and try to talk to a living person (Interviewee No. 8)."

The reluctance to buy from a brand that only has a chatbot to interact with its customers negatively impacts their likelihood of completing future orders. Mainly because they feel that the chatbot is not able to understand their complex requests properly or does not know how to help them, and they feel hopeless when there is no other way to contact the company.

"Once, actually a few months ago, I bought something on an unnamed brand e-shop and the product did not fit, so I went through the whole return process and everything seemed fine, until the moment I took the package with that item to the parcel service, the shipping ticket that was sent to me was faulty. There was no other way to contact the company than to use a chatbot. It was as useful as the FAQ. No need to have a chatbot in that case. I tried to find any other way to contact them. I looked everywhere, in their app, and official webstore, I even searched it on Google. I found other customers with similar problems and found out how they got through. It took me hours! Besides, I was unsuccessful and frustrated, and I was also left with an expensive dress that did not fit me. So, I had to pay for international shipping that was supposed to be free. I deleted the app, and I think I will never shop with them again (Interviewee No. 11)."

Since the impact of failed communication on brands could be fatal, customers were asked the maximum acceptable conversation time to resolve their issue via chat with the chatbot before they rated the interaction as "bad." Half of the respondents stated that the maximum time they are willing to spend communicating with a chatbot, reformulating or giving details before they obtain the required answer is only 5 minutes. One-quarter would be willing to spend up to 10 minutes before leaving the conversation unsatisfied. One-tenth would give the chatbot even 15 minutes. Another one-tenth is willing to accept a conversation 30 minutes long, and the last one-twentieth stated that up to one hour of trying would be acceptable before they give up. The average time before abandoning the chatbot would be 12.5 minutes, but it must be considered that the influence of the one-sided extreme is included.

"If there should be no bad feelings connected with the chatbot interaction, the conversation should take under 5 minutes (Interviewee No. 15)."

When participants were asked what they would be willing to use a brand's chatbot for after their experience, each participant mentioned at least one thing that would normally be found in FAQs or specific information that could be found in other parts of the website, but the chatbot makes it easier for customers. They would ask questions about a product, about shipping or returns policies. They mentioned using chatbots to subscribe to a newsletter or mailing list, as well as a way to find a human customer service agent. Some stated more complex issues, such as resolving an order problem, making a complaint, making a purchase, or paying a bill.

"Mostly, I would ask about shipping and return policies (Interviewee No. 27)."

"I would use a chatbot when looking for a contact to a specific branch or if I need help to decide which product is the most suitable for me (Interviewee No. 21)."

The most important thing for customers when interacting with a brand's chatbot is that the option to transfer the customer to a human customer service agent is always available. If the customer service center is closed at the time of the interaction, the chatbot should inform the customer of this and provide a specific date and time when the customer service agent will be available to communicate with the customer.

"If the company is aware that its bot is not AI-powered, it should only be used to find out the matter of the issue and then pass the query on to a human customer service agent (Interviewee No. 31)."

The second most important thing, according to the participants, is that it should be clear that the interaction is with a robot. This requirement is reinforced by customers if the chatbot is a humanized one, which could appear to customers as a live customer service agent. Customers seem to care whether the brand's chatbot is friendly and helpful. Prewritten questions and the possibility to only click on the preferred option and obtain required answers effortlessly and in a very short period are essential. Among other things, customers appreciate when the chatbot has a voice command feature.

"I like the communication smooth and quick. If there is a list of prewritten statements, or possibility to dictate the message it is always better (Interviewee No. 1)."

None of the participants are pleased to see chatbots show up on the brand's website when they are not actively looking for help, and half said that uninitiated chatbots annoy them, mainly when the chatbot is covering a tremendous amount of the website and the customer must take action and close the chat.

"I know where to find a chatbot when I want to interact with it. They are always in the same place on websites. But when they pop up and I need to shut them down, it is annoying (Interviewee No. 18)."

On the other hand, they would be pleased to see more use of chatbots on the brand's profiles on social media. As mentioned before, they favor personal, one-on-one communication and expect fast communication that does not require a significant effort on their part. Nearly three-quarters of participants said they either received no response or an unsatisfactory response from the brand they attempted to contact. As far as the non-answer option was concerned, it was mainly communication via social networks. Participants added that they feel stronger bound towards a brand or any other company if they interact with them via social media profiles. More than nine-tenths of participants mentioned social networks as the most suitable communication channel to reach audiences from their generation and said they would welcome it if they obtained at least some response from the branded profile

on social media profiles. The rest of the respondents felt neutral towards social media as a communication channel.

"When a company responds to my comment or message on any social media platform, I feel seen and valued, not just one of many. When company profile messages are blocked, they can seem cold and impersonal. It looks like they do not care about their audience. I do not mind if a human or bot replies to me, at least I do not have to look for other ways to contact the company (Interviewee No. 29)."

It is possible to see a difference in the use of intelligent technologies among users who, according to their own words, are more introverted.

"I prefer interacting with a chatbot, self-service panel, or any other technology over communicating with people. I do not like interpersonal interactions (Interviewee No. 17)."

Compared to extroverts:

"Interpersonal communication is one of the most natural things for me, instead of writing or trying to formulate a command correctly, I talk to a live person on the phone or visit a store in person. Communicating with a robot is frustrating for me, especially because I have to type a command or question precisely so that it is understood, and a relevant response is provided by the chatbot. What I hate most is getting an answer to something completely different from what I am asking, accompanied by a question about whether it can help me with something else. You do not get that with a human being. I miss subtle nuances in the conversation that I have not yet observed in chatbots, such as showing a sense of humor, understanding more complex sentences, or giving room for clarification (Interviewee No. 13)."

Self-reported introverts represented only one-fifth of the respondents; the rest considered themselves ambiverts and extroverts and were inclined to communicate with a live agent.

Conclusions and discussion

Innovative marketing should be part of every marketing strategy since it is one aspect of the brand's success, even in an ever-changing market. Hence, innovative marketing not only satisfies the customers' unmet needs at a given moment, but also predicts future or unknown requirements and creates customers' needs that they do not even know about yet. Zulfikar et al. (2022) emphasize that building strong customer relationships is essential for long-term success and sustainability in today's competitive marketplace. According to Yang and Battocchio (2020), positive brand communication is a key tool for strengthening relationships and building customer loyalty to a brand.

In this highly competitive digital age, innovative marketing approaches and the use of innovative tools such as chatbots are ways to make a positive impact on the minds of customers while trying to optimize marketing budgets. To be effective in digital marketing, brands need to have the capacity to adapt to changes and to take advantage of new opportunities. Brands conceptualize and execute new ideas through the ability to innovate. The ability to adapt to customer behavior and new technologies while maintaining a strong customer focus, is essential to great marketing. Leveraging innovation as a chatbot can drive marketing campaigns. As Rydiger (2023) mentions, a clear focus on customer-centric experiences and innovative marketing practices through the use of chatbots allows brands to design and serve customers in a way that enhances those experiences.

It is obvious that chatbots are going to be more and more utilized by businesses. For brands to capitalize on the implementation of chatbots as a customer communication and service channel, it is critical to understand customer preferences and take a customer-centric approach to bot strategies. Kemp et al. (2021) perceive the space primarily in fostering lasting relationships and building customer trust in the brand. This paper aimed to identify the preferences of Generation Z's interaction with brands' chatbots. The paper, therefore, provided an understanding of how a brand can build strong relationships with Generation Z customers through an innovative marketing approach that uses chatbots to communicate with customers 24/7/365.

Betz (2019) points to the fact that Generation Z is looking for quick, customized responses and personalized incentives from brands. They value real-time, one-on-one interactions and appreciate brands that respond quickly and thoughtfully to their feedback. The best solution for brands is an AI platform that enables and integrates chatbots and human support from the customer support team to provide instantly scalable, premium pre-sale shopping support. The result is the best possible customer

experience throughout the customer journey, increasing loyalty, satisfaction, and revenue. A great example of this type of chatbot are the marketing chatbots created by Microsoft, e.g., Zo, Xiaoice, Rinna, and Ruuh (each tailored to a specific country and all designed to appeal to a late 20+ audience). Those chatbots are able to enter a conversation with relevant facts on topics such as celebrity, sport, or finance, as well as being empathetic and humorous. Using sentiment analysis, it can adapt the way it speaks and responds based on positive or negative signals from the customer. It stores details from previous conversations with users, bringing up topics from those interactions in later conversations. It can be used as an AI avatar to engage with customers through platforms, e.g., WhatsApp, WeChat, Slack, and Skype. This chatbot represents exactly what Generation Z customers expect from a chatbot brand interaction.

The Kik chatbot is another great example of using chatbots the right way. The chatbot-powered sales platform enables real-time customer interactions with branded chatbots from companies like Sephora and H&M. There is already almost an infinite number of ways chatbots can serve Generation Z customers. They can skip the line and take your Starbucks coffee order with a few message exchanges. They can provide recipe recommendations based on your grocery shopping history, etc. And that is just to name a few of the ways that chatbots are already being used.

On the other hand, it is always better to have the option to escalate the interaction to a human agent if anything goes wrong. This need increases significantly as the chatbot's error probability increases. The article contributes to the debate regarding Generation Z's perception of brands and helps identify possible pitfalls involved in communicating with chatbots. Mostly, the Czech Generation Z wants to interact with the chatbot like a human being, which is not suitable for a rule-based chatbot. One of the most significant shortcomings of chatbots, according to participants, is their inability to understand the customer's inquiry properly. The frustration among Generation Z is more than skyrocketing while interacting with an uncomprehending chatbot if there is no possibility of being transferred to a human agent or contacting the company any different way. Cleave et al. (2016) and Taghizadeh et al. (2013) discuss the negative impact of poor responses on customer-brand relationships. Poor communication and insensitive responses can alienate customers from the brand, leading to customer dissatisfaction and abandonment.

On the contrary, basic tasks can be performed by rule-based chatbots efficiently as expected and without errors. The inquiry complexity and customer expectations from this customer service channel determine the suitability of the chatbot type. This can be determined by the situation in which the chatbot is used. If the customer enters the interaction with negative emotions, for example, associated with dissatisfaction with the product or service, then the dissatisfaction with the chatbot's services automatically deepens and it would be better to use human services.

The aforementioned Czech Generation Z customer is the one who is always online and has access to global offerings. A recent study by eMarketer found that out of 500 marketing organizations surveyed, only 7% use AI-powered chatbots, which are the most relevant for interacting with Generation Z. The findings of the research conducted for this paper proved that this percentage will grow (Powderly, 2021).

Increasingly, the future of personalized brand digital marketing of brands is looking more and more like a mix of artificial intelligence, human empathy, and conversational skills. Brands' chatbots will have all the time in the world to engage in conversations with customers online whenever they want to have a conversation. This is great news for Generation Z and even better news for the brands who are interested in reaching them.

Limitations and suggestions for future research. While this paper can be seen as having contributed to the existing literature on chatbot-customer Z interaction and has expanded our understanding of the expectations of Generation Z customers while communicating with brands, it has some limitations.

A valuable upgrade of this research model would be the implementation of neuromarketing using a control group of respondents which will be done in the next research.

The possibility of generalizing the findings to the entire Czech Generation Z population is minimized due to the study's qualitative character and the sample size. To support these findings, future studies could adopt larger samples and quantitative methods and measures.

This study was conducted in the Czech Republic, where Generation Z customers usually have many opportunities to observe and engage with brands' chatbots. Future research to determine whether the same patterns are found among Gen Z customers could be carried out in different contexts and other countries. A deeper analysis of the various uses of brands' chatbots, whether they are text-based, such as messaging apps, mobile apps, web pages, or spoken variations of chatbot interaction, could be conducted to explore other possible patterns of behavior with each type of chatbot and further advancements in innovative customer service tools.

Further research could compare the difference in brands' chatbot interaction according to customer personality type, which would not be based solely on self-reported data. Customer segmentation based on the big five personality types might enlighten the differences in brands' chatbot interaction with customers because extrovert and introvert personalities display very different behaviors.

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Till death do us part. Do customers cheat on brands?

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Abstract: *Some companies, based on the beliefs of their managers, aim to obtain solely loyal customers in the hope that these customers will always buy only one brand and never cheat by buying a competitor's brand. However, a growing body of empirical research suggests that this may be an overly positive expectation and that this marketing strategy can run counter to the nature of the consumer. To scrutinize the sole loyal buyer idea, this study empirically examines the phenomenon of duplication of purchase, which suggests that customers not only buy from repertoire but also that brands share customers in proportion to their market share. Data were drawn from two consumer packaged goods categories: beer (10 brands), soft drinks (6 brands), and eight NUTS2 regions. Using a robust sample of 3,488 customers from a consumer panel and many sets of data approach, the research replicated significant patterns of duplication of purchase in both categories studied and across all regions. The findings support the notion that while consumers are likely to repurchase a brand previously purchased, they also frequently diversify their choices between competing brands. Therefore, the study confirms the generalisability of duplication of purchase behaviour in different categories and geographies, providing critical information for marketing strategy and brand management. It is a strategy that goes against the principles of how buying behaviour works to try to persuade customers to buy from one single brand for the rest of their lives. A great deal of corporate resources will be wasted in the pursuit of sole loyalty.*

Keywords: *Brand, customer loyalty, duplication of purchase, natural monopoly, marketing strategy.*

JEL Classification: *M31, L66, L22.*

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Introduction

Imagine a bustling supermarket. Among his other purchases, John regularly picks up his favourite beer brand, appearing to be a loyal customer. The following week, enticed by a different offer, he selected an alternative brand that diverged from his last choice. Should a marketer be angry and write off John forever? Some authors consider this to be a marketing failure, but there is a growing body of empirical evidence that temporary customer defection does not necessarily mean that the customer is no longer loyal. In fact, it seems to be more of a normal switching behaviour than a signal of relationship-ending cheating. This could be explained by the broader phenomenon of duplication of purchase (DoP), wherein consumers typically select brands habitually from a preexisting repertoire. This idea challenges the traditional belief in exclusively loyal consumers,

instead emphasising that individuals generally maintain a portfolio of brands they patronise rather than remaining devoted to just one.

Marketers who understand the DoP make altered decisions and allocate resources differently to those who do not (Kennedy & McColl, 2012). They view their competition more widely and do not focus much on any specific competitor brand. Moreover, they understand that brands usually compete with all other brands in the market, approximately in line with the size of the other brands (Dawes, 2008). If there is a deviation from the pattern called partition, then this information provides valuable insight into competitive positioning. Partitions tend to indicate amplified competition and can inform pricing, communication, and distribution tactics. It can also provide a basis for category definition based on buying behaviour rather than product features. Some marketers might build their marketing strategy based on their own assumptions about target market and product feature fit. But the DoP analysis can show who the real competition is and which brands make up a category. Overall, empirical knowledge of customer choices provides marketers with an understanding of market structure and the competitive environment.

1. Theoretical background

Duplication of purchase is based on the theory of stochastic preference introduced and described by Bass (1974). Stochastic preference suggests a probability distribution over options rather than a clear-cut ranking. For instance, an individual may slightly prefer option A over B, but there is still a possibility of selecting B due to random factors. This theory is reflected in NBD-Dirichlet model which among other things explains the DoP in more detail and assumes that customers choose from a small portfolio of the available options (Scriven et al., 2017). This split loyalty is then observable in consumer behaviour, where the customer selects stochastically from a repertoire of brands (Dawes, 2008; Naami et al., 2022; Romaniuk & Dawes, 2005). Consequently, each brand shares its customer base with other brands in the category in line with the size of those other brands.

Patterns of DoP were initially observed in the media consumption behavior. The observation of these patterns first occurred in the context of magazines, as noted by Agostini (1962). Subsequently, this phenomenon was also detected in television programmes and channel viewing, with Barwise and Ehrenberg (1988), and Jardine et al. (2016) providing evidence of this. Furthermore, DoPs have been identified in the realm of listening to radio stations, as evidenced by studies conducted by Lees and Wright (2013) and Winchester and Lees (2013). Interestingly, the manifestation of DoP extends beyond traditional sectors of consumer behaviour and has been observed in areas such as gaming and gambling, as explored by Lam and Ozorio (2013), leisure activities (Scriven et al. 2015) as well as in the consumption of arts, as demonstrated by Hand and Riley (2016). Surprisingly, DoP has even been detected in the field of sports, as described by Fujak et al. (2018). Recent studies have also shed light on DoP patterns in music consumption, specifically in relation to genres, artists, albums, and songs (Anesbury et al., 2023). In addition, there have been investigations into DoP in the context of mobile app usage, as conducted by Graham et al. (2021), and its presence in the non-profit sector (Faulkner et al., 2023).

Most research conducted in this field has predominantly focused on the domain of fast-moving consumer goods (FMCG), which is a logical choice considering the sector's significant business impact. Studies covering a range of 12 categories, ranging from rice to cat food, in both the US and UK markets have discovered instances of duplication in every category, as revealed by Dawes (2016). Furthermore, Graham (2009) provides a dynamic perspective on the DoP phenomenon in the instant coffee market by comparing its development over a six-year period. This analysis is invaluable as it sheds light on the temporal evolution of the metric in relation to market share. Tanusondjaja et al. (2016) took a comprehensive approach by examining entire categories and the co-purchase of products within them, revealing some intriguing pairs that were bought in a manner different from what was expected. Evidently, the DoP pattern serves as a framework for not only analysing the competitive dynamics between brands, but also for understanding the synergistic or antagonistic interactions among different product categories. In a study conducted by Trinh et al. (2019), DoP was detected when analysing the relationship between the country of origin within the category of wine and butter products. Most buyers were found to purchase wines or butter

from multiple countries, and popular countries tend to exhibit a higher level of DoP than less popular countries. Dawes (2014) focused on examining the cigarette market in the USA. His analysis revealed a strong correlation between brand penetration and average brand cross-purchasing over all investigated years. This finding suggests that brands with higher penetration rates also tend to have a higher level of cross-purchases with other brands.

Research on duplicated purchases has touched on the category of beverages, both alcoholic and nonalcoholic. One of the first to describe purchase duplication in the soft drink category was Bass (1974). The study demonstrated that the rate at which consumers switched from soft drink Brand A alternative brands (B, C, D, etc.) was in line with the market penetration of these respective alternative brands. Dubé (2004, 2005) empirically showed that households regularly select multiple soft drink products and multiple units on a given trip, thus seeking variety. Sjostrom et al. (2014) analysed cola and other flavoured carbonated beverages to compare light (or diet) and regular versions. Their results suggest that both light and regular brands are similar in terms of market performance, which implies that typical behavioural patterns, such as DoP, appear for light brands, as they appear for regular brands.

Moderate research on DoP in the alcohol product category has been carried out. Dawes (2008) conducted an interesting research study involving a sample of 620 individuals who consumed beer. The purpose of this investigation was to identify and analyse purchasing behaviour patterns among these beer drinkers. Interestingly, the study findings not only revealed the existence of DoP, but also shed light on the concept of double jeopardy. It was observed that larger brands in the beer industry not only have a larger customer base, but also boast a higher number of loyal customers. This implies that these larger brands enjoy a double advantage in terms of customer acquisition and retention. Romaniuk and Dawes (2005) discovered the occurrence of DoP across various wine price tiers. Furthermore, it was observed that price tiers with higher penetration rates also exhibited a higher level of sharing with other price points, thereby indicating the presence of a pattern. Cohen and Tataru (2011) later examined the structure of the French wine market with a sample size of 300 participants. Their findings echoed those of Romaniuk and Dawes (2005), who also identified similar patterns among price tiers. Wilson and Winchester (2019) conducted research on 25,000 wine customers from a customer panel. Their findings demonstrated the presence of a DoP pattern among the top 20 leading brands in the category, with only a few exceptions that suggested the existence of market partitions. These market partitions represent brands that, while similar in terms of usage, possess distinctive characteristics that set them apart from the rest of the market (Romaniuk & Dawes, 2005).

Understanding variations in the form of market partitioning is useful to understand circumstances in which the DoP principle does not apply. In their study of television viewing, Barwise and Ehrenberg (1988) found significant differences in projected patterns for Spanish-language and religious programmes. Many years later, another partition has been discovered. Consumers who prefer goods associated with free trade can show a stronger preference for brands within the free trade domain than implied by the DoP (Winchester et al., 2015). Lees et al. (2016) found minimal partitions in the limited choice of banking products across banks in Australia and New Zealand. Furthermore, recent evidence suggests that these partitions tend to persist over time (Anesbury et al., 2021). Scriven et al. (2017) observed partitions in both the UK butter and spread market and the sugar confectionery market. Naami et al. (2022) reviewed 33 DoP studies, of which 39% were conducted in the US, 36% in the UK, 21% in Australia and 6% in France, New Zealand and Japan. India, Macau, Singapore, and an anonymous European country were involved in 3% of the studies. This clearly shows that this line of research is prevalent in developed countries and that, apart from France and one English-speaking European country, no studies have been conducted within Europe.

In light of the lack of research within the beverage industry (especially in the category of beer and soft drink category) and the complete lack of studies targeting the Central European market, this study is designed to address these research gaps. With a focus on beverages category in small Central European country, two key research questions have been asked:

RQ1: Do brands share customers consistent with duplication of purchase?

RQ2: Based on the duplication of purchase analysis, are there any meaningful deviations?

Once these questions are answered, one can ask further if there are more patterns of consumer behaviour. Another empirical generalisation comes in handy for this type of analysis: natural monopoly (not to be confused with the natural monopoly in microeconomics). Natural monopoly in marketing context describes how often category buyers purchase multiple brands and how these increase when market share decreases (Sjostrom et al., 2014). Simply put, smaller brands have more cheating customers than large brands. The pattern occurs generally because the leading item of choice is more likely to attract light users of a category, and heavier users duplicate their activities more (Scriven et al. 2015). This analysis uncovers the power of brands with higher market share and great market power.

2. Research methodology

Despite the tendency of academics to prioritise novelty, some have called for ongoing replication or extensions (Bergkvist et al., 2023; Lehmann & Bengart, 2016). The dissemination of replications and extensions safeguards the literature against the uncritical acceptance and promotion of erroneous and questionable findings (Hubbard & Armstrong, 1994). An individual study conducted in isolation is essentially devoid of meaning and utility (Bettis et al., 2016). Replication or extension calls have also been observed in the field of marketing (Easley et al., 2000; Evanschitzky et al., 2007; Sharp et al., 2017). Due to the lack of replication, a significant portion of the knowledge base in marketing may be based on unsubstantial evidence (Zinkhan et al., 1990). The range of conditions under which a result holds must be examined and expanded regularly. Makel and Plucker (2014) asserted that although the replication approach may potentially impede creativity, factual accuracy supersedes novelty. In essence, excessive emphasis has been placed on techniques and novelty, overshadowing the importance of valuable and practical knowledge (Sharp et al., 2017).

Methods of replication go hand in hand with the many sets of data (MSOD) approach, which is, in fact, an inbuilt replication. Inbuilt replication refers to the practice of including replication within a series of experiments to assess the stability of the results (Gernsbacher, 2018). The same applies outside the laboratory conditions. In the real world, the use of more than one data set provides a solid foundation for marketing researchers to build their knowledge (Wind et al., 2013). Due to MSOD and its potential for generalisation, marketers can understand the market mechanisms they need to manage a brand. Thus, if the study design allows, it is desirable to use multiple datasets for validation across time, country, region, product category, or industry. Uncles and Kwok (2013) described three dimensions in which the stability of the phenomenon can be verified. These are the content (product), spatial (space), and temporal (time) dimensions. This study uses content and spatial dimensions to test the presence of DoP in two product categories and eight NUTS2 regions.

Data were provided by Behavio Labs, a private market research company, using their consumer panel database. Consumer panels have been used regularly for this type of study (Dawes, 2016; Trinh et al. 2023; Wilson & Winchester, 2019). Data were exported for research purposes in March 2022. In total, 3,488 were available for analysis, of which 1,742 were women. In terms of age distribution, the largest group falls within the range of 30 to 44 years, constituting 1,233 consumers, closely followed by the 45 to 64 years age group with 1,214 respondents. The 18 to 29 years and 65+ years categories are less represented, with 691 and 350 individuals, respectively. Observing the educational background, most of the customers completed high school (2,471). The sample included 841 university graduates and 176 individuals with only an elementary school education. The town sizes varied: 1,049 respondents were from towns with over 50,000 residents, and 941 were from towns with up to 2,000 residents. The other categories fell between these extremes. Respondents were proportionally distributed among regions, as can be seen in the table below (Tab. 1). Lastly, the marital status of the respondents showed a significant number of singles (705) and those living unmarried (514). The divorced category included 483 individuals, while the widowed category was the least represented, with 175 individuals.

Let us now define the variables used in this study: brand penetration, duplication, and estimated duplication. Penetration is measured as the proportion of panel buyers

Tab. 1: NUTS 2 regions representation in the sample

	Central Bohemia	Central Moravia	Moravia-Silesia	Northeast	Northwest	Prague	Southeast	Southwest
Respondents	445	392	397	490	367	438	557	402

Source: own

who drink beverages from a particular brand at least occasionally. Additionally, duplication is the proportion of buyers of one brand who buy another brand. The estimated duplication has been calculated from the DoP law (Dawes, 2016; Tanusondjaja et al., 2016), expressed as:

$$b_{X|Y} = D \times b_X \quad (1)$$

where: $b_{X|Y}$ – the proportion of brand Y buyers who also buy X; D – the duplication coefficient, the average of the observed duplications divided by the average penetration of all brand; b_X – brand X's penetration.

3. Results and discussion

3.1 Results

The results show that there is a higher degree of co-occurrence between large brands and a lower degree with a smaller brand. This finding is consistent with brand sharing patterns, as predicted by the duplication of purchase law: sharing is in line with brand size. The phenomenon is observable in the scatter plots in Fig. 1, each representing one category. As brand penetration increases, so does average duplication. A detailed duplication matrix is available in Tabs. 2–3.

Deviations from the expected levels of sharing can denote the presence of a partition where brands share at an unusually higher or lower rate than expected (Ehrenberg et al., 2004). In Tab. 2, values that deviate more than 10% points from average are marked in bold. There are a few examples of this that are worthy of comment. Brand F is a traditional Czech beer brand with an international reputation and a higher price. It has a lower than expected co-occurrence with brands G, D, and H, which are local beers with lower to medium prices. Consumers of brand H buy brands D and C more than expected. Similarly, buyers of brand D buy beer brand C, indicating that these brands are jointly in the buyers' choice repertoire, forming a possible competitive segment. However, when considering this partition, one should proceed with caution. The deviation has been small (11% or 12%, respectively).

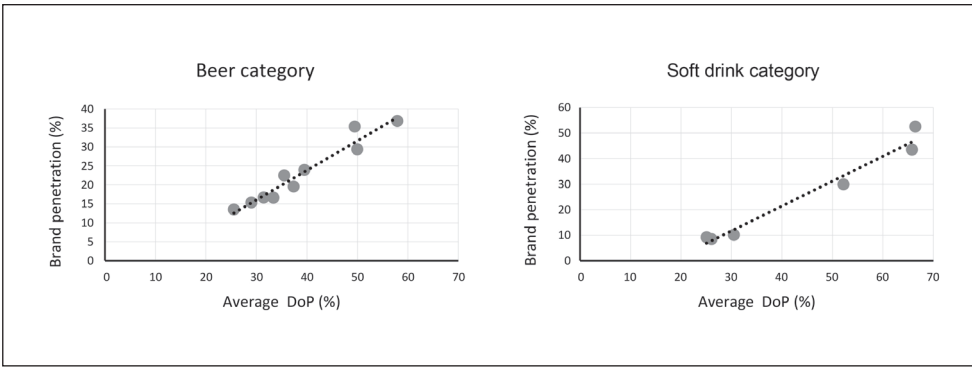

Fig. 1: Penetration and duplication of purchase link in beer and soft drink category

Source: own

Tab. 2: Duplication of purchase in the beer category

% of buyers	Who also bought									
	B	F	A	G	J	C	D	H	I	E
Brand B		50	46	39	32	31	28	30	24	20
Brand F	52		44	**29**	29	29	**19**	**22**	24	22
Brand A	58	53		37	34	36	31	34	29	20
Brand G	60	43	46		31	34	30	31	25	28
Brand J	52	45	45	33		33	27	27	25	28
Brand C	59	52	54	42	38		41	41	32	25
Brand D	62	41	55	43	37	**48**		41	32	25
Brand H	67	47	60	44	37	**49**	**42**		34	30
Brand I	58	56	56	39	36	41	34	37		32
Brand E	55	59	44	49	46	36	31	37	36	
Average duplication	58	49	50	40	36	37	31	33	29	26
Penetration	37	35	29	24	22	20	17	17	15	14
Estimated duplication	62	60	50	41	38	33	28	28	26	23

Note: Co-occurrence values deviating more than 10% points from average are shown in bold.

Source: own

Furthermore, previous studies propose to consider only deviations greater than 20% that are managerially viable to act effectively (Tanusondjaja et al., 2016).

In the soft drink category, in contrast to the beer category, more significant partitions were observed (Tab. 3). First, there is an interesting pattern within the most popular brand 2, with the highest market penetration of 53%. Consumers of this brand buy other brands significantly less than expected. To be precise, their co-occurrence deviation is higher than 10% points from the average. Brands with unusually high duplication generally share functional similarity. For example, in an analysis of switching among soft drinks, it was found that there was a greater tendency for individuals to switch between different types of diet soda than there was for them to switch from diet sodas to regular sugar-sweetened soft drinks (Bass, 1974). Therefore, the unusual pattern of duplication for brand 2 could be explained by several facts. First, this brand is representative of the traditional national brand in the cola type category. It also has a lower sugar content compared to two competing brands (1 and 3) that have almost the same level of sugar. Additionally, it has a significantly different composition from liquoricelitract that other brands of cola do not contain.

In addition, brands 4, 5 and 6 show significantly higher co-occurrence (bottom right quadrant). This can be easily explained by the types of brands that represent this subsegment. There are brands of functional drinks or so-called energy drinks. The other three brands 1, 2 and 3 represent carbonated cola-type drinks. We have separated the table by quadrants to explain duplication among the subsegments. Energy drink users also buy cola-type drinks intensively (bottom left quadrant) but it is not that extensive in the other way around (top right quadrant). For example, 67% of energy drink brand 5 consumers buy cola brand 2. In contrast, only 13% of cola brand 2 buyers buy energy drink brand 5.

There are also two brands in the energy drink category that share more than the expected number of customers. Exactly, more than 20% points from the average duplication. Both brands are selling their drinks at a very similar price point. These brands are national compared to international brand 4. Not only is

Tab. 3: Duplication of purchase in the soft drink category

% of buyers	Who also bought					
	Brand 2	Brand 1	Brand 3	Brand 5	Brand 4	Brand 6
Brand 2		**49**	**39**	**13**	**12**	**11**
Brand 1	59		52	**15**	16	**13**
Brand 3	69	75		**19**	18	16
Brand 5	67	65	56		**39**	**52***
Brand 4	66	75	58	**43**		**38**
Brand 6	71	65	56	**62***	**41**	
Average duplication	66	66	52	30	25	26
Penetration	53	43	30	10	9	8
Estimated duplication	91	75	52	18	16	15

Note: Co-occurrence values deviating by more than 10% points from the mean are shown in bold; values deviating by more than 20% are shown with *; sub-segment quadrants are shown in grey in the cells.

Source: own

brand 4 global and slightly more expensive, but it typically sells in 0.25 l cans, compared to two national brands sold in 0.5 l cans. Clear functional and price differences distinguish these brands from the third competitor. All three brands enjoy a similar level of distribution and are available in most typical retail outlets across the country.

To test the predictive power of the duplication model (1), the estimated duplications ($b_{X|Y}$) were counted for both categories (last row in Tab. 2 and Tab. 3). We started by calculating the D – duplication coefficient, which reflects the total amount of purchase duplication that occurs in the product category. In the category of beer, the coefficient is D = 1.694 and in the category of soft drinks it is D = 1.729. Finally, the D-coefficient is multiplied by each brand's observed penetration, providing the expected duplication. Now, we can analyse the correlation between average duplication and estimated duplication. It was r = 0.969 in the beer category and r = 0.984 in the soft drink category. However, the correlation is not a sole indicator of the predictive power of the model. To prove its weak ability to show power, we must mention that the correlation between average duplication and penetration is the same (r = 0.969 in the beer category and r = 0.984 in the soft drinks category). This is because the estimated duplication is just multiplied by D. For this reason, most authors use more than one method of evaluating goodness-of-fit. Driesener et al. (2017) proposed several ways from which one is the calculation of mean absolute deviations (MAD). MAD measures the accuracy of the prediction by averaging the alleged error or the absolute value of each error (Khair et al., 2017) and is expressed as:

$$MAD = \frac{\sum|y_1 - y_t'|}{n} \quad (2)$$

where: y_1 – the observed values; y_t' – the model; n – number of observations.

The mean absolute deviation for estimated duplication and average duplication in the beer category is 0.037 and 0.113 in the soft drink category. This indicates the solid predictive power of the DoP law Formula (1).

To confirm the existence of DoP across regions (spatial dimension), a further analysis has to be applied. The original data sheet was segmented by NUTS2 regions, and for each region, the DoP was calculated, as well as the penetration of the brands in the region. The correlation between these two variables was then calculated to demonstrate the relation of duplication with penetration, as predicted by the DoP law (Tab. 4).

Tab. 4: Duplication of purchase in the soft drink category

Code	NUTS2	Beer	Soft drinks
CZ01	Prague	0.932	0.971
CZ02	Central Bohemia	0.978	0.960
CZ03	Southwest	0.989	0.987
CZ04	Northwest	0.982	0.985
CZ05	Northeast	0.970	0.994
CZ06	Southeast	0.954	0.992
CZ07	Central Moravia	0.969	0.975
CZ08	Moravia Silesia	0.976	0.951

Note: Correlation for brand penetration and average duplication.

Source: own

Once we know the customers naturally cheat on brands, we can further discuss with whom are they cheating the most. One perspective to consider is to analyse consumer loyalty in a specific category and their affinity toward brands of varying sizes and asses the existence of natural monopoly. The available data do not provide information on how intensively customers buy in the category. Thus, we cannot identify the light or heavy category buyer. However, we can observe how larger brands attract customers who select from a smaller repertoire. In Fig. 2, there are plots of the average number of brands bought and the brand penetration. The correlation is evident to the naked eye: the smaller the beer brand, the more switching buyers it attracts (Fig. 2 – left). The same story can be illustrated in the soft drink category (Fig. 2 – right). The largest brand with a market penetration of 53% has customers buying 2.2 brands on average. On the contrary, customers of the smallest brand with a penetration of 8% are buying 3.9 brands on average.

This phenomenon can be tested on a spatial dimension similar to that of the DoP. In Tab. 5 there are correlations for brand penetration and average number of brands bought in each investigated regional market. The results show a high negative correlation between brand penetration and the average number of brands bought by customers. In short, the larger the brand in the penetration metrics, the higher

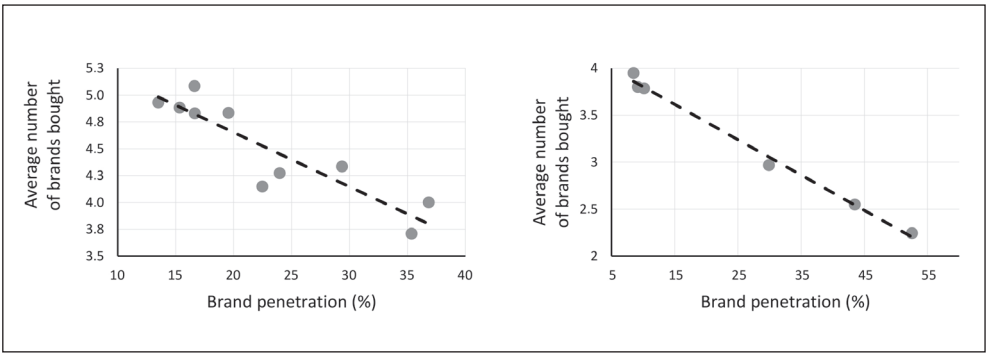

Fig. 2: Natural monopoly in beer (left) and soft drink (right) category

Source: own

Tab. 5: Natural monopoly in the soft drink category

Code	NUTS2	Beer	Soft drinks
CZ01	Prague	−0.945	−0.988
CZ02	Central Bohemia	−0.972	−0.952
CZ03	Southwest	−0.968	−0.997
CZ04	Northwest	−0.917	−0.971
CZ05	Northeast	−0.904	−0.980
CZ06	Southeast	−0.879	−0.981
CZ07	Central Moravia	−0.880	−0.969
CZ08	Moravia Silesia	−0.911	−0.988

Note: Correlation for brand penetration and average number of brands bought.

Source: own

the chances that the brand customers have a smaller brand repertoire.

3.2 Discussion

We asked if brands share customers consistent with DoP and the results support the positive answer to this research question. We found the pattern previously observed in many research settings outside and inside the fast-moving consumer goods category. It holds across two product categories and eight regions. The correlation of brand penetration and average duplication indicates that smaller brand customers duplicate their purchases with larger brands more extensively than vice versa.

The second research question asked whether there are any meaningful deviations. With the help of average duplication, we found small deviations from expected values in some beer brands, but these differences are more or less negligible. Conversely, in soft drink category there is a market leader with unusual deviation, which could be explained by its large availability in shops as well as in restaurants in tap form. Another factor is its local origin and the fact that this drink is part of the national history. Furthermore, a significant partition has been found to divide the category into cola drinks and energy drinks. This is in line with previous research. Products or brands with unusually high duplication generally share functional similarity (Dawes, 2016). Duplication of more than 20% points was found for two brands of energy drinks, suggesting a partition within a partition, which may be informative for brand managers responsible for these two highly competitive brands. It is worth considering what threshold should be used to distinguish between significant and negligible differences. In our case, we used 10% to spot the difference between the cola and energy drink category, which would be impossible to see when the 20% rule is applied. We suggest future researchers to apply both on same data set to see layers of competition in duplication purchase data.

Another phenomenon worth discussing is the fact that the estimated duplication model overestimated the duplication of the leader and follower brands, then accurately estimated the duplication of the third largest brand, and then more or less slightly underestimated the rest of the brands. This is surprising, as this slight inaccuracy has also been observed in previous research (Anesbury et al., 2018; Mecredy et al., 2021; Winchester et al., 2015). This should be a focus of future research. It is possible to look for ways to adjust the slope of the line for a more accurate way of modelling the DoP law.

This paper provides solid empirical evidence of the validity of the duplication of purchase and natural monopoly phenomenon, which is linked to the NBD-Dirichlet, which builds its logic on the theory of stochastic preferences. It is yet another agreement with the theory supporting the idea that stochastic models provide a good description of the reality of customer behaviour. The cycle of confirming theoretical foundations with real-world data is important in terms of advancing our knowledge of brand choice and consequent market structure. The results show that

theories based on the idea of super-customer loyalty may be in need of revision.

Every study has limitations, and this one is no exception. First, the temporal dimension of the replication design is omitted. It would be useful to follow the development of the DoP over time and see if this law is permanent. Another considerable limitation is the absence of real retail transaction data, which is only represented by survey data. These data are naturally subject to weaknesses, such as inaccurate memory of the respondent. Furthermore, data on the frequency of brand and category purchases is missing. Therefore, it is impossible to explain the real reason for the smaller repertoire size of the largest brand buyers. Data on category intensity would answer if there is a loyalty on play or light category buyers behind this reduced repertoire. The only possibility is to use an analogy with other studies and estimate the cause. Another limitation coming from the absence of purchase frequency is the inability to calculate market share when analysing natural monopoly. However, while market penetration used in this study is not the same metric as market share, a number of studies show their close relation (Graham, 2009; Romaniuk et al., 2018). All of these limitations represent future opportunities for research in this field.

Conclusions

Understanding the basics of consumer behaviour is essential for any successful marketing manager. It provides the foundation for sound marketing strategies that leave no room for misconceptions that could lead the company astray. The research presented here corrects the delusional idea of the sole buyer. These single-brand loyal shoppers are almost non-existent in the marketplace. Moreover, it is not an imperfect behaviour that should be corrected by marketing efforts. Rather, it is the norm for customers to change brands, as John did in our hypothetical story at the beginning of this article. The results provide valuable information to marketers. First, there is no need to exhaust resources trying to change natural customer behaviour. Second, competition is much broader, and unless there is an evident partition in the analysis, the focus should be on the whole competitive landscape. To be more specific, in the beer market there are no significant partitions that would signal the need for specific segmentation. On the other hand, in the soft drink category, there is a strong partition dividing the market into two smaller segments, cola drinks and energy drinks. Third, it is okay for the brand to have customers who also buy other brands, and this is normal for large and small brands. The idea of nurturing loyalty is worth pursuing but should not be pushed to extremes. Rather than forcing some customers to buy only one brand all year, nudging other customers to make a purchase twice a year instead of once is a more realistic strategy.

Since replication and extension are essential for the development of generalised knowledge, this research helps to achieve this. DoP has been extended and verified to be useful for mapping competing brands in the categories of beer and soft drinks in the Central European country market, categories and regions largerly under-researched in current literature. Furthermore, the data presented evidence supporting the existence of the second empirical generalization, natural monopoly pattern. Our results suggest that popular brands are more likely to attract consumers with a smaller brand repertoire in the respective product category, in contrast to less popular brands. Hence, the theoretical contribution of this study lies in its beneficial role in supporting empirical generalization of DoP and also with all the limitations in mind, natural monopoly.

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