The Efficiency of CEE Countries Innovation System

Davor Vlajčić, Margareta Gardijan Kedžo, Davor Filipović

Three decades after transitioning to market economies, Central and Eastern European (CEE) countries continue to lag behind the "old" EU member states in terms of economic convergence. This persistent gap is compounded by a pronounced shortfall in innovation capacity. An innovation system that is well-coordinated, well-funded, and responsive to technological trends enables a country not only to integrate novel maritime technologies but also to contribute to their development. Without such systemic capacity, countries risk falling behind in critical sectors, including shipbuilding, port logistics, environmental compliance, and digital maritime infrastructure. This study evaluates the efficiency of public, private, and higher education sectors R&D expenditure, with a particular focus on the temporal dynamics of innovation efficiency. Using Data Envelopment Analysis (DEA), the paper assesses cross-country variations in innovation system performance, while Malmquist Index is used to detect intertemporal changes of countries productivity. The findings reveal that while the innovation gap between CEE countries and older EU members remains significant, there are encouraging signs of progress. Notably, Estonia, Slovenia, and Poland have exhibited the most substantial gains in innovation productivity. In contrast, Latvia and Slovakia have stagnated at levels similar to those of the late 1990s, and the Czech Republic, Hungary, and Lithuania have seen considerable declines. Persistent inefficiencies in public and higher education R&D systems pose ongoing challenges, although private sector investment has played a partial compensatory role in offsetting these structural weaknesses.

KEY WORDS
~ CEE countries
~ Innovation
~ Efficiency
~ Productivity
~ DEA

University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia
e-mail: dvlajcic@efzg.hr
doi: 10.7225/toms.v14.n03.w05

Received: 2 Jun 2025 / Revised: 7 Jul 2025 / Accepted: 18 Jul 2025 / Published: 25 Jul 2025

1. INTRODUCTION

Innovation can be understood as the outcome of coordinated efforts among various actors, activities, interactions, and amplifications within a systemic environment (Granstrand and Holgersson, 2020; Lundvall, 2024; Lundvall et al., 1988). The relationships among these agents and institutions are defined by flows of knowledge, finance, human capital, regulation, and commerce (Niosi, 2002). Yet, both researchers and policymakers often overlook the importance of harmony—or a "symphony"—between these agents. As Nooteboom (2000) suggests, institutional governance and interdependence can be disrupted by friction in human interactions, ultimately lowering system efficiency. Inefficiency has often been linked to broader politico-economic structures. Magnusson and Ottosson (1997) argue that administrative bureaucracy and institutional inertia – common traits of socialist heritage – undermine innovation. Conversely, proponents of socialist systems emphasize the potential advantages of hierarchical structures and concentrated decision-making, which may reduce noise in knowledge transfer and, paradoxically, enhance systemic efficiency (Mandel, 1986). This debate is particularly relevant in the context of transition economies in the European Union. Over the past three decades, former planned economies have undergone extensive political and economic transformations, with EU accession representing the most radical institutional and industrial shift. However, the lack of full convergence with older EU members calls into question the effectiveness of these transformations (Cavallaro and Villani, 2021). Even decades after abandoning centralized systems, many Central and Eastern European (CEE) countries continue to bear the legacy of planned-market structures. While these countries now enjoy access to global markets and international capital, they still struggle with limited indigenous innovation capacities and remain heavily reliant on imported technologies. Insufficient R&D investment further impairs the development of absorptive capacity, casting doubt on their ability to implement new technologies effectively (Prokop et al., 2021). The persistence of outdated technologies and productivity challenges risks trapping CEE economies in low value-added industries. Given these dynamics, many scholars have identified CEE countries as a unique case for studying shifts in innovation system efficiency. Consequently, research in this area is growing (e.g., Dobrzanski, 2018; Bielicki and Leśniak, 2016; Dzemydaitė et al., 2016; Yesilay and Halac, 2020; Jurickovaa et al., 2017; Kirankabeş and Erkul, 2019; Ciołek and Golejewska, 2022; Ciocoiu et al., 2025; Mitu and Stanciu, 2023). Addressing the technological gap and fostering domestic innovation capabilities requires both internal R&D efforts and collaboration with external actors (Prokop et al., 2021). The dismantling of old industrial infrastructures has resulted in a decline in public R&D funding. This leaves negative effect on higher education sector since it is predominantly publicly funded. However, international organizations and donor agencies contributed by supporting modernization initiatives in higher education, mitigating lack of public R&D funds. At the same time, the entry of foreign companies has introduced private capital and its role in developing R&D capacity across the region. However, underdeveloped institutional infrastructure continues to challenge the efficiency of investments in R&D capacity-building.

This research investigates how effectively government, business and higher education sectors in CEE countries allocate and utilize their R&D funds in order to stimulate breakthrough innovations. Furthermore, it examines the inter-temporal changes of CEE countries' innovation efficiency. This will allow to detect trends in CEE countries' productivity. Finally, this paper aims to find which sector is the most inefficient. This will help in finding an optimal balance between public, private, and academic R&D investment to build a more effective and productive innovation system. Assessing innovation performance remains a high priority for policymakers, especially during periods of economic uncertainty. A deeper understanding of innovation performance allows for the creation of targeted strategies to strengthen innovation in knowledge-based economies. Benchmarking, identifying best practices, and pinpointing inefficiencies are essential tools in designing effective policies. To explore variation in innovation system efficiency, this paper employs Data Envelopment Analysis (DEA). Given its capacity to explain inter-temporal shifts in innovation productivity, Malmquist Index is also analysed. This paper contributes to a better understanding of how systemic national capabilities influence technological advancement, and consequently advancement in maritime technologies.

The rest of this paper is structured as follows. In the second section, a review of the latest literature on this topic will be provided. The third section is devoted to the formulation of the research question. The forth section contains the methodology. In the fifth section, the results will be analysed and discussed. The last section contains the conclusion.

2. LITERATURE REVIEW

It is widely accepted that the availability of resources and their efficient internal allocation are key drivers of global competitiveness (Klingebiel and Rammer, 2014). The importance of innovation system efficiency has been highlighted in numerous studies (Broekel et al., 2018; Carayannis et al., 2016; Chen et al., 2014; Łącka and Brzezicki, 2021; You and Teirlinck, 2024). Much of the existing literature focuses on the cross-regional and cross-country comparisons of the efficiency levels, with the goal of identifying systems that demonstrate an optimal input-output ratio. However, this optimal ratio does not necessarily correspond with a country's level of development. For instance, Cai and Hanley (2014) compared the technical efficiency of innovation systems in developed and developing countries. Their findings revealed a counterintuitive trend: the developing economies, such as China and India, were found to use their resources more efficiently than the advanced economies like the United States, the United Kingdom, and Austria. Nonetheless, since innovation systems encompass multiple stages, inefficiencies of the developed countries in the production area are offset by a stronger efficiency in the commercialization phase (Carayannis et al., 2016; Chen and Guan, 2012). Static analyses provide only a snapshot of the system efficiency and are therefore inadequate for capturing the dynamic nature of innovation process (Chen et al., 2014). To address this limitation, the Malmquist and Luenberger productivity indices are often employed to measure changes in the efficiency together with changes in the technological frontier, thereby capturing the changes of productivity over time. These methodologies decompose productivity changes into two components: technological change (shifts in the production frontier) and efficiency change (catch-up effects) (Chen et al., 2014). A positive shift in the production frontier typically reflects technological upgrades at the observed input/output mix, often achieved through specialization of the national knowledge base, whereas the catch-up effect captures changes in a country's relative efficiency. Guan and Chen (2010), using a DEA–Malmquist approach, assessed productivity changes across Chinese provinces from 2000 to 2003, revealing limited growth in R&D productivity. Similarly, Thomas et al. (2009) analysed productivity growth in 22 countries, finding that—excluding the United Kingdom—most countries experienced technological progress. Notably, China and South Korea stood out due to substantial gains in efficiency, which contributed significantly to their productivity growth. In a study of 27 EU member states, Łącka and Brzezicki (2021) found that innovation system productivity grew more significantly in countries that joined the EU after 2004. This increase was primarily driven by gains in efficiency rather than shifts in the technological frontier. Zabala-Iturriagagoitia et al. (2021), in their analysis of 36 countries between 2011 and 2018, found a decline in the productivity growth linked to the innovation over time, suggesting a weakening effect of technological progress. Fare et al. (1994) investigated productivity growth in 17 OECD countries between 1979 and 1988, showing that the United States outperformed others due to shifts in the technological frontier. Japan, on the other hand, was identified as the most productive country in the sample, largely due to above-average growth in efficiency. More recently, Ndicu et al. (2024) evaluated innovation productivity in 28 African countries from 2010 to 2018. Their findings indicate that 18% of the national innovation systems exhibited improvements in both the catch-up effect and frontier shifts. In another study, Mensah et al. (2023) observed convergence in innovation performance across Africa, primarily driven by technology catch-up. You and Teirlinck (2024) examined and compared the productivity of China, Europe, and the United States between 2015 and 2019, with a focus on the effects of the industrial specialization and diversification. Their findings reveal a U-shaped relationship between the industrial diversification and productivity growth in China, predominantly driven by improvements in efficiency. For European countries, industrial specialization showed a similar U-shaped effect on R&D efficiency and productivity, while industrial diversification exhibited an inverted U-shaped relationship. Notably, no significant impact of specialization or diversification was found on overall improvements in R&D performance.

The efficiency of innovation systems in Central and Eastern European (CEE) countries has received considerable scholarly attention in recent years. Numerous studies compare the performance of CEE countries to that of other EU member states, OECD countries, and developing economies, revealing diverse and often contrasting outcomes. This focused interest stems from the distinctive features of innovation systems in the region. Factors such as deindustrialization, underdeveloped R&D capacity, and constrained financial resources have raised critical questions regarding the effectiveness of R&D expenditure. Dzemydaitė et al. (2016) highlight substantial regional disparities in innovation performance, identifying 33 regions as inefficient in converting R&D investments and human capital into technological outputs, while only 7 regions demonstrated efficient utilization of these resources. Similarly, Dobrzanski (2018) reports widespread inefficiencies in both public and private R&D spending across most CEE countries, although Romania and Slovakia are noted for their relative proximity to the technological frontier. This suggests that the targeted increases in the R&D investment could potentially mitigate these inefficiencies. Bielicki and Leśniak (2016) emphasize the pivotal role of EU structural funds—approximately €170 billion allocated to CEE countries between 2007 and 2013—in fostering innovation. Their study assesses the degree to which these funds were strategically used in accordance with national innovation policies and key expenditure indicators. In a related vein, Zemtsov and Kotsemir (2019) argue that entrepreneurial activity and geographical proximity to major innovation centers significantly influence technology creation, enabling beneficial interregional knowledge spillovers. Regional disparities in innovation efficiency are also evident in Russia. Firsova and Chernyshova (2020) explore the relationship between innovation output variables – such as the product volume, patenting activity, and the investment levels as inputs —and conclude that, while economies of scale play an important role, the breadth of the resource base, rather than resource efficiency alone, contributes more significantly to regional innovation performance. A country-specific analysis by Jurickovaa et al. (2017) positions the Czech Republic within a moderately efficient category of innovation systems, though notable gaps remain in the areas of intellectual assets and research capabilities. Kravtsova and Radosevic (2012) similarly observe that productivity in CEE countries often falls short of expectations, attributing inefficiencies to broader socio-economic and political factors that hinder the effective transformation of technological and production inputs into economic output. Kirankabeş and Erkul (2019), in their study of 52 NUTS-2 regions across CEE from 2001 to 2012, identify technological change and capacity expansion as primary drivers of total factor productivity (TFP) growth. Nonetheless, regional inefficiencies persist. Mitu and Stanciu (2023) find that medium-sized government structures tend to exhibit better expenditure performance and R&D efficiency, suggesting that governance models influence adaptability to innovation investment. Finally, a study by Ciołek and Golejewska (2022) analysing the efficiency of innovation systems in Polish subregions reveals that while a few regions demonstrate a strong innovation performance, the majority underperform. Their findings suggest that regional efficiency is shaped by the presence of an innovative milieu, spatial proximity to innovation hubs, and levels of industrial engagement. Conversely, high unemployment and weak social capital emerge as significant barriers to innovation efficiency.

3. RESEARCH QUESTION

Institutional transformation is a challenging process demanding deep and structural transformation, such as those which transition countries are passing since abandoning system of planned economy (Perényi et al, 2020). According to Ireland et al (2008), interference of socialist norms, beliefs, values, etc., with capitalist rules, regulations, laws, have created dissatisfaction with the emerging capitalist economic system. Poverty, political corruption, low savings and investment, locked-in transition countries in a vicious circle of inefficiency (Rosenberg, 1994; McMillan and Naughton, 1992). System legacy built over several decades, can't be transformed overnight (Kornai, 1998; Aslund, 2013). People inertia, bureaucracy and a sharp fall in the GDP prolonged system transformation. Political elites continue promoting planed-economy values, such as government intervention (Radosevic and Yoruk, 2018). Incompatibility of inherited large vertically integrated industrial sectors, with entrepreneurial capitalist system, generated high transaction costs (Radosevic and Yoruk, 2018). Furthermore, advantages enjoyed by large business groups, such as easier access to financial capital, had disappeared. Thus, they were dismantled and transformed into unrelated small and medium-sized enterprises intended to be an agent of industrial change (Radosevic, 1999). However, newly formed innovation system was missing technical and market infrastructure to rely on. Consequently, CEE innovation system failed to develop technological activities at the enterprise level (Freeman and Reid, 2006). Since the late 1970s, the productivity in the CEEs has steadily declined, a trend closely linked to the increasing inefficiencies of the communist regime. The painful decline in productivity was further compounded by the transitional shock experienced by CEE countries during the 1990s. Van Ark and Inklaar (2006) argued that the sharp GDP drop in these nations will significantly delay their catch-up with developing countries—and he even warned that such progress might never occur. His observations were built upon trends at the time, such as large macroeconomic instability, GDP fall, institutional inertia, consumption driven growth. Despite starting from different baselines, the sharp GDP declines in all CEE countries ultimately reset government R&D spending to similar levels. However, despite the early 1990s' transition shock, these nations eventually aligned with the market-based R&D model.

The former lack of clear distinctions between government and industry evolved into the emergence of three distinct sectors: government, industry, and higher education. Historically a leader in R&D performance, the government, faced challenges such as poor managerial competence and mismatches between its priorities and business technologies. According to Bahl et al. (2021), these challenges have further reduced absorptive capacity and hindered learning, effectively keeping high-quality, cutting-edge technology out of reach for CEE countries. As Lacasa et al. (2017) notes, the limited access to advanced technologies has resulted in an overreliance on imitative development and a persistent focus on activities that lag behind the technological frontier. Due to the diminishing importance and dominance, as well as technological lag, state-led R&D model loses its momentum, which resulted with fading of public R&D funding. However, as time passes, stabilization of the political and economic system enabled financial resources and government investment in R&D. Furthermore, by adopting practices from the countries they aspired to—EU, CEE countries achieved coordination between the public and private sectors. According to Foreman-Peck and Zhou (2022), foreign funding crowded in many national subsidies at the firm level. While some CEE countries recorded marginal effect central government funding on innovation activates, Lithuania and Slovakia had extremely positive outcome of government expenditure. Similar findings were recorded in research of Hartsenko and Sauga (2012) and Masso and Vahter (2008). Due to the initially low level of government funding and a lack of technological sophistication, attention shifted from domestically led government efforts to private, predominantly foreign, led technological modernization. Private capital yielded some positive effects, but these were primarily seen through enhanced absorptive capacity rather than innovation (Popescu, 2014; Misztal, 2020; Radosevic, 2017; Radosevic, 2022). In fact, the increase in productivity in CEE countries is largely due to mastering imported technologies and knowledge, along with improvements within foreign companies themselves (Radosevic, 2022). While developed EU members allocate over 70% of their R&D expenditure to innovation, CEE countries devote only around 40%, with the majority of their R&D spending directed toward acquiring machinery and equipment (Radosevic, 2017). In short, productivity growth was driven by enhanced production capabilities rather than by innovation. Foreign-led technological modernization did not enable these countries to catch up with developed European nations. In fact, according to Kriaucioniene and Ragauskas (2008), foreign capital had the opposite effect—it triggered the disappearance of advanced components of the value chain. Eapen et al. (2019) highlight the limited effect of external knowledge, arguing that foreign private companies fail to alter the mandates of domestic firms and to bring about significant functional upgrades. Education has an essential role in stimulating a country's level of competitiveness (Nistor and Deaconu, 2012; Sekuloska, 2014; Yeravdekar and Tiwari, 2014). Although strong basic research skills and a robust education system were legacy from previous system, they could not compensate for the outdated R&D capacities that neither public nor private capital succeeded in building. However, the importance of higher education for R&D is increasing rapidly, despite the initial disparities. The growth of the higher education sector clearly indicates an institutional convergence toward a market-based economy model. All previously mentioned highlights ambiguity over government, private, and higher education efficiency of R&D funds allocation, thus question is raised:

How efficiently does government, private, or higher education use their R&D funds, did efficiency of their R&D expenditure changed over time. Finally, which sector - government, private, or higher education - use their R&D funds most efficiently.

4. EMPIRICAL RESEARCH

When evaluating the performance of a single unit over time, we analyze its productivity. However, to compare performance among similar units, we assess their relative efficiency. A unit might improve its productivity by performing better than in previous periods, yet simultaneously experience a decline in efficiency if other comparable units show even greater improvement. Therefore, efficiency is inherently a relative measure, indicating a unit's standing within its industry and reflecting industry trends. Data envelopment analysis (DEA) is a methodology for evaluating the efficiency of homogenous and comparable units, typically referred to as decision making units (DMUs). These DMUs must utilize the same inputs to produce the same outputs. Conceptually, the goal is to achieve the largest possible outputs with the smallest possible inputs. Production possibilities set P, is defined as a set of all pairs of inputs (x) and outputs (y) for which the following holds (Cooper et al., 2011):

$$P = \{(x, y):\ x \geq X\lambda,\ y \leq Y\lambda,\ \lambda \geq 0\} \tag{1}$$

where λ is a semi-positive vector from ℝm which satisfies constraints based on the assumed returns to scale (constant λ =1, increasing λ>1, decreasing λ <1). Efficiency is assessed against the efficient frontier, which envelops the entire production possibility set. Efficient units are those that lie on this frontier, representing the best practices achievable within the observed sample. The foundational and most widely used DEA models are the CCR (Charnes-Cooper-Rhodes) model and the BCC (Banker-Charnes-Cooper) model. Both models yield efficiency scores within the interval [0,1], where a value of 1 indicates efficiency and values below 1 signify inefficiency. This research employs the BCC model to estimate the innovation efficiency of selected countries from 1998 to 2019. The BCC model was chosen because it accommodates variable returns to scale, which is a more appropriate assumption for this specific analysis. Furthermore, an output orientation is utilized. The output-oriented BCC model is structured as follows: Consider n homogenous DMUs, each using inputs $x_i, i = 1, \dots, m,$ to produce outputs $y_r, r = 1, \dots, s$. For each DMU, the following mathematical programming model is solved:

subject to:

$$Max\ \phi \tag{2}$$

$$\begin{aligned}
&\textstyle\sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{i0}, \forall i = 1, \dots, m \\
&\textstyle\sum_{j=1}^{n} \lambda_j\, y_{rj} \geq \phi y_{r0}\,, \forall r = 1, \dots, s \\
&\textstyle\sum_{j=1}^{n} \lambda_j = 1 \\
&\lambda_j \geq 0, \forall j = 1, \dots, n
\end{aligned}$$

where the optimal value of ϕ for each DMU is the maximal value of output expansion achievable with the given level of inputs and within the production possibilities set. Let $\theta = 1/\phi$ be the efficiency score. The λ values represent weights assigned to specific DMUs in constructing a virtual benchmark. This benchmark is a convex combination of efficient DMUs, indicating which inputs should be reduced or outputs increased for an inefficient DMU to become efficient.

This paper evaluates the innovation efficiency of eight European Union countries: Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia, over the period 1998-2019, using yearly data. This sample selection is justified by the high comparability of these countries. They all underwent a transition from planned to market economies around the early 1990s and subsequently joined the European Union together in 2004, after approximately 15 years of market-based system experience. This shared trajectory of economic and institutional transformation makes them an ideal group for comparative analysis.

The innovation efficiency of these countries is measured using six variables: four inputs and two outputs.

Inputs:

- Business expenditure on R&D (BERD) as a percentage of GDP,
- Government expenditure on R&D (GOVERD) as a percentage of GDP,
- Higher-education expenditure on R&D (HERD) as a percentage of GDP,
- R&D personnel.
- Outputs:
- Number of patents per 1000 R&D personnel (PATENTS)
- Number of scientific and technical journal articles per 1000 researcher (S&T PAPERS).

All data were extracted from the Organization for Economic Co-operation and Development (OECD) – Science Technology and Innovation database. The R&D data in OECD database, used in this publication, have been collected in accordance with the standard OECD methodology for R&D statistics, as outlined in the OECD Frascati Manual. During the observation period, the data collection methodology underwent one revision (in 2015). However, the methodological changes were minor, and data comparability has been preserved. To ensure transparency and comparability, countries are required to provide detailed metadata, which are stored in the Sources and Methods Databases (OECD, 2015). The input and output variables are visualized in Figures A1-A6 in the Appendix.

The innovation efficiency of the selected countries is evaluated using a pooled sample approach. This means that each country in each year is treated as a distinct DMU. This results in a sample of 176 DMUs (8 countries over 22 years). Consequently, the efficiency of these DMUs is assessed relative to a meta-frontier, which is constructed from the best recognized practices across the entire sample period. This meta-frontier is assumed to represent the best achievable practices within the 1998-2019 timeframe. This approach is also driven by the sample size; a within-year efficiency analysis, given the small number of countries per year, would lead to insufficient discrimination, resulting in nearly all units being identified as efficient.

To evaluate the development of DMUs over time within the DEA framework, we revert to productivity analysis using the Malmquist index (MI). When a single meta-frontier serves as the reference for measuring meta-efficiencies in a pooled sample, the Malmquist index simplifies to the ratio of meta-efficiency scores, as proposed by Portela and Thanassoulis (2010). Typically, the MI is calculated for two consecutive periods, t and t+1. In this analysis, we evaluate productivity growth in each period relative to a base period, which is 1998. Therefore, let θ_{j0}^{m} be meta efficiency of DMUj in the base period t=0 (in our case, 1998), and θ_{jt}^{m} its meta efficiency in time t, t ≠0. Then modified meta - Malmquist index can be calculated as

$$MI_{0,t}^{j} = \frac{\theta_{jt}^{m}}{\theta_{j0}^{m}} \tag{3}$$

The Meta-Malmquist index (3) offers several advantages: it is circular, computationally simpler, and can be applied to variable returns to scale (VRS) technology without leading to infeasible solutions. Moreover, it facilitates straightforward comparisons between units and across different time periods. The value of this Malmquist index indicates the productivity change of a specific DMU relative to the base period: MI>1: Productivity has improved, MI<1: Productivity has worsened, MI=1: Productivity has stagnated. The Malmquist index can be calculated and decomposed in various ways. It can be demonstrated that a DMU's meta-efficiency is the product of its within-period efficiency and the efficiency of its within-period virtual benchmark relative to the meta-frontier. This latter component is termed the technology gap, which quantifies the discrepancy between the maximum production possibility achievable within a specific year and that achievable across the entire analyzed period.

In the decomposition of the Malmquist index, two key components are often analyzed: efficiency change (EC) and technological change (TC). Let θ_{jt}^{t} be the within - period efficiency and TG_{jt} a technological gap, of a DMU j in time $t \in \{1,..,T\}$. Then

$$MI_{0,t}^{j} = \frac{\theta_{jt}^{t} \times TG_{jt}}{\theta_{j0}^{t} \times TG_{j0}} = \frac{\theta_{jt}^{t}}{\theta_{j0}^{t}} \times \frac{TG_{jt}}{TG_{j0}} = \begin{matrix} \textit{efficiency} \\ \\ \textit{change} \end{matrix} \times \begin{matrix} \textit{technological} \\ \\ \textit{change} \end{matrix} \tag{4}$$

The efficiency change (EC), also known as the catch-up effect, indicates whether a DMU is becoming more or less efficient relative to the contemporaneous efficient frontier. If EC > 1 for DMUj at time t, it means DMUj has moved closer to its within-period frontier compared to the base period. Conversely, if EC < 1, the DMU has moved further from its within-period frontier, indicating a decline in its relative efficiency. Technological change (TC), or the frontier-shift effect, reflects shifts in the within-period efficient frontier. A TC > 1 suggests technological improvement, meaning the within-period frontier has moved closer to the meta-frontier, indicating an advancement in the maximum achievable production possibilities. If TC

< 1, there has been a degradation of technology or a movement away from the meta-frontier. A TC = 1 indicates technological stagnation. This component highlights the discrepancy between the within-period frontier and the overall meta-frontier, illustrating how the best practices of a specific year compare to the best practices observed across the entire study period.

While the Malmquist index is a powerful tool for analyzing productivity growth, its disadvantage lies in the necessity to calculate distance functions. Various methods can be employed for this calculation. However, as noted by Kirikal et al. (2004), the linear programming approach, similar to DEA and proposed by Färe et al. (1994), is the most commonly used method. It's important to acknowledge that the choice of different methodologies for calculating these distance functions can lead to divergent conclusions regarding efficiency changes (Grifell-Tatjé and Lovell, 1995).

Figure 1 presents the efficiency scores (meta-efficiency) of the DMUs from the pooled sample, which were obtained using the BCC model. These values range from 0 to 1, with 1 indicating pure technical efficiency.

Figure 1. Efficiency scores of the DMUs from the pooled sample (Source: Authors)

Figure 2 illustrates the values of the Meta-Malmquist index (MI), which quantify the changes in productivity for the selected countries over the years, using 1998 as the base year for all measurements. Specifically, each plotted value represents the ratio of a country's efficiency score in a given year (from 1999 to 2019) to its efficiency score in 1998.

Values around 1 indicate a constant performance relative to the base year. A rise in productivity compared to 1998 is indicated by values positioned above the dotted horizontal line. The red line in Figure 2 specifically represents the boundary shift component of the MI, also relative to the 1998 base period.

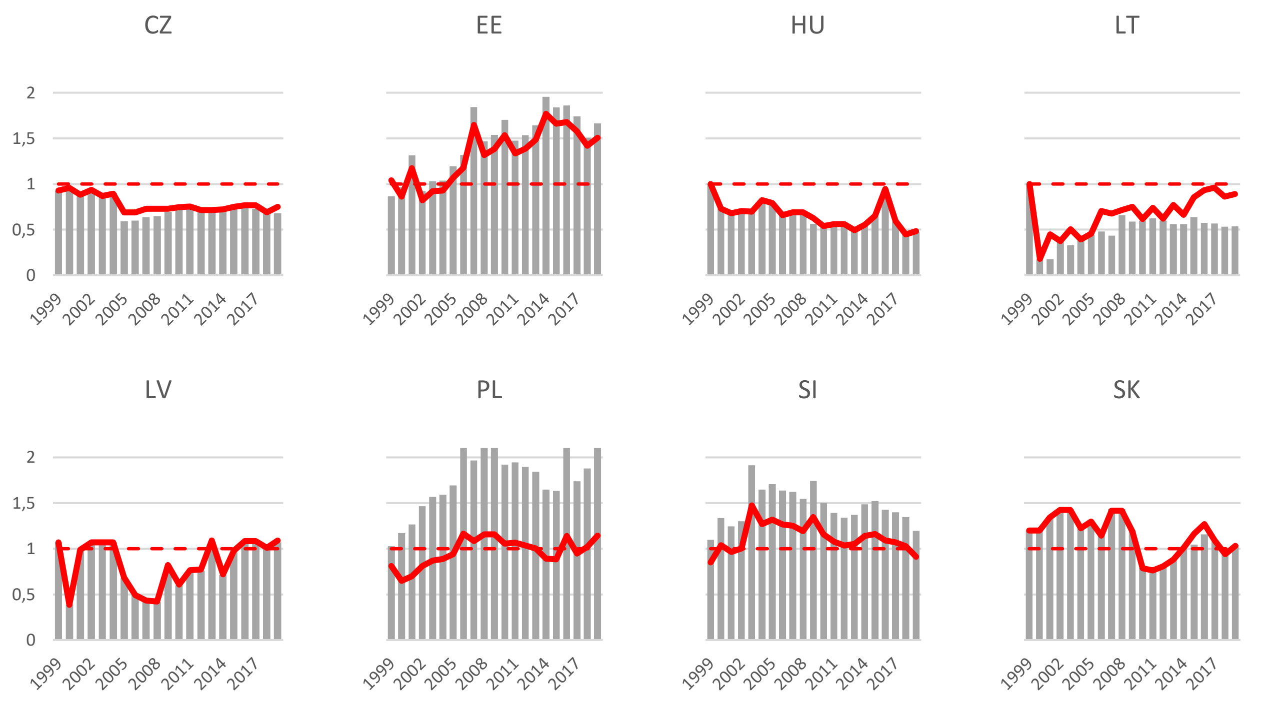

Figure 2. Meta-Malmquist productivity index and boundary shift (base 1998) (Source: Authors)

5. RESULTS AND DISCUSSION

The low R&D capacity of the CEE countries appears to be ending, as ongoing investments are beginning to transform its legacy. However, during observed 20 years majority of CEE countries failed to use R&D funds efficiently. Thus, innovation system transformation is slow and gradual.

The results in Figure 2 shows productivity trends in chosen CEE countries in a period from 1998-2019. Productivity in Poland increased throughout the observation period, although there were some minor setbacks between 2009 and 2014. During that time, productivity continued to rise, but at a slower pace. In 1998, Poland had the second lowest efficiency base (Figure 1) among the observed countries, making it the second least efficient CEE country. However, over the years, enhanced technological capacities and steadily improving efficiency (Figure 1) have driven significant productivity gains. By the end of the observed period in 2019, Poland's productivity had doubled compared to its 1998 levels (Figure 2). These results confirm previous findings of Gomułka (2023), who also advocates Poland transition process as a success story. Notably, there has been a slowdown in productivity growth coinciding with a reduction in government R&D spending (Appendix, Figure A3) – a trend that began during the global financial crisis when public R&D budgets were cut. Nevertheless, this decline in government expenditure was offset by robust growth in business R&D (Appendix, Figure A1), which accelerated overall productivity gains. This positive trend also aligns with a substantial inflow of foreign direct investment (FDI) bringing advanced technology (Petrariu et al., 2013). Poland recorded the strongest FDI inflows among CEE countries, with major industrial players such as Samsung, Volkswagen, Opel, and LG establishing their R&D centres adjacent to production facilities. Their investments have significantly boosted the nation's production capabilities.

Estonia is another country that demonstrated consistent productivity growth over the 20-year period, despite some minor slowdowns after 2014 (Figure 2). Starting from the lowest efficiency base among the countries observed, Estonia initially ranked as the least efficient (Figure 1). Much of its progress can be attributed to expanding technological capacities. This complement previous findings of Masso & Tiwari (2024). The country's innovation efforts were primarily driven by business and higher education R&D expenditure (Appendix, Figure A1; Figure A2). The technological frontier was steadily advanced by private investors—mainly foreign—such as ABB Estonia, GPV Estonia, Ericsson Estonia, and Elcoteq. At the same time, domestic players like Cybernetica and local universities kept pace. Following Estonia's accession to the EU, universities gained momentum by effectively utilizing structural funds to support research and innovation. In 2013, Estonia saw a significant drop in business R&D expenditure, mainly due to the conclusion of a major oil industry project that had fuelled substantial investment from 2010 to 2012 (Statistics Estonia, 2013). Rather than signalling a broader crisis, the decline marked a structural adjustment following a period of exceptional, short-term private spending. Despite the reduction, overall productivity remained largely unaffected, indicating that the earlier R&D spike had only a temporary impact. By the end of the observed period in 2019, Estonia's productivity had grown 70% comparing to 1998 levels (Figure 2).

Slovenia is yet another country that experienced consistent productivity growth throughout the observed period (Figure 2). Like the previous two countries, it started from one of the lowest efficiency bases in the sample (Figure 1). Productivity rose sharply and peaked in 2004, after which it continued to grow, though at a slower pace. Similar trends were found in previous research of (Nye, 2021). This growth was largely driven by the business sector, which dominates R&D activity (Appendix, Figure A1), and is responsible for technology progress which drives productivity in Slovenia. Domestic companies—such as Krka, Gorenje, Hidria, and TPV Group—serve as the main R&D investors (Sila et al, 2017), while foreign firms like Lek (owned by Novartis) play a supporting role. As a result, fluctuations in foreign direct investment had only a limited impact on overall productivity levels. However, the global financial crisis had a notable effect on Slovenia (Martin et al, 2015). Due to declining economic output and a delayed adjustment in employment levels, productivity per worker fell. Interestingly, Slovenia's patenting activity and scientific publication output peaked in 2003, followed by a steady decline. One possible explanation lies in the changing structure of R&D employment: since 2004, the number of technicians and support staff has grown faster than the number of researchers, potentially influencing research outcomes and innovation intensity (OECD, 2024). By the end of the observed period in 2019, Slovenia was 20% more productive comparing to 1998 levels (Figure 2).

Compared to the three previously presented productive countries, Hungary shows a continuous decline in productivity over the observed period (Figure 2). Starting from one of the highest efficiency bases in 1999, Hungary reflected its early and efficient transition to a market economy (Figure 1). This goes in line with OECD (2004) findings. Since then Hungary's performance deteriorated significantly. These negative trends reinforce findings of Vokoun and Dvouletý (2025). By 2019, its productivity had fallen to just half of its 1998 level, largely due to increasing inefficiencies and technological regression at the observed input/output mix. In the first decade, R&D spending was primarily driven by the business sector, though government and higher education also played important roles (Appendix, Figure A1). Strong domestic demand during this period was fuelled by rising minimum wages, public sector pays, and infrastructure investment. However, by 2005, growing public debt and budget deficits led to austerity measures that curtailed public and higher education R&D spending (Grosu et al, 2022). Business R&D, in contrast, continued to grow, supported by domestic firms like Richter Gedeon and foreign investors such as GE, Samsung, Huawei, and Audi, with only a slight dip in 2014. Despite dynamic firm creation, Hungary's innovation outcomes remained weak. Patent activity, scientific publications, and in-house innovation were all limited. The OECD (2010) noted that innovation based on internal R&D was particularly low. While FDI brought in foreign technologies, Hungary's limited domestic R&D capacity—especially the absence of innovative medium-sized firms—hampered the country's ability to fully absorb and build upon these technologies, contributing to its broader decline in productivity. The efficiency of Hungarian SMEs remains below 60% of that of large domestic corporations. Their innovation capacity ranks in the bottom third among EU Member States, falling well behind the EU average. Improving SME productivity will largely depend on the wider adoption of advanced digital business solutions and greater investment in energy efficiency (Magyar Nemzeti Bank, 2022).

Slovakia is another country that experienced productivity growth—but only up until 2009 (Figure 2). This growth was driven by improvements in efficiency (Figure 1) and technological advancement at the observed input-output levels. However, after 2009, a sharp decline in efficiency caused productivity to deteriorate. This goes in line with Braha et al (2015) conclusion that Slovakia has exhausted the key drivers that previously fuelled its technological growth. Often referred to as the "Detroit of Europe," Slovakia hosts several major automotive manufacturers, including Volkswagen, Kia Motors, PSA Peugeot Citroën, and, since 2015, Jaguar Land Rover. Due to its strong reliance on global demand and foreign investment, the global financial crisis severely impacted Slovakia's already modest R&D spending. At the same time, a growing imbalance emerged between the number of researchers and the overall R&D workforce, as more technical and support staff—who contribute less directly to productivity—were hired. Slovakia has heavily relied on EU funding to support its R&D, with EU resources covering about 35% of projects. The country's R&D investment closely mirrors the EU funding cycle (Morvay et al, 2021). In 2015, at the end of a programming period, R&D investment peaked at 1.2% of GDP. But in 2016, as the new EU funding cycle began slowly, public sector R&D spending dropped sharply—falling back to levels last seen in 2011 (Appendix, Figure A3). This decline was so steep that even steady growth in business R&D could not offset it. As a result, by 2019, Slovakia's productivity had returned to the approximately the same level as in 1998 (Figure 2).

Results for Czech Republic indicate perfect efficiency at the start of observed period, in 1998 (Figure 1). High level of efficiency Czech Republic maintained until 2004. After that, a strong decline in efficiency was recorded. Similar trend can be found in the level of technology capabilities. Thus, previously stated dictate the trends in productivity (Figure 2). During the entire observed period, Czech Republic did not record growth in innovation productivity level. At the end of the observed period, Czech Republic productivity fell for 33 percent compared to 1998. From 2005 onwards, Czech Republic records growing number of R&D employees, however growth trend is higher in employment of non-R&D - technical stuff. This result goes in line with research of Lewis & Fall (2017) which also indicate on poor resource utilisation. During the entire period, business sector had strong dominance in R&D expenditure (Appendix, Figure A1). Despite sustained public R&D funding, a steady increase in business R&D activities (Škoda Auto, ČEZ, Avast, Škoda Transportation, and Zentiva, Bosch, Honeywell, IBM, Microsoft, Panasonic, Daikin, Foxconn, etc.), and an ambitious reform agenda since 2007, the Czech innovation system has yet to fully capitalize on its investments. The country has seen improvements in R&D intensity and a significant number of new science & engineering graduates and doctorate holders. However, the quality of scientific output, high-impact publications, and patent production remains low by international standards (Appendix, Figure A5 – A6). This underperformance, coupled with insufficient cooperation between businesses and public research organizations—evidenced by minimal business co-funding and few co-invented patents—deters the emergence of domestic innovation leaders (Kadlec and Blažek, 2015). Additionally, weaknesses in research evaluation methodologies, venture capital access, and international knowledge transfer further hinder the science base’s attractiveness, ultimately limiting the potential of the Czech innovation system (Government of the Czech Republic, 2016). The Czech Republic significantly lags behind most EU Member States in scientific quality. This performance varies by field: while aeronautics and space, energy, transport technologies, and biotechnology boast high scientific excellence and international collaboration, they are not traditional areas of Czech specialization. Conversely, the country's strongest specialization in food, agriculture, and fisheries yields many publications but with limited impact. National R&D targets focus solely on public funding, leaving private R&D investment under-addressed. This gap threatens the adoption and rigorous implementation of policies to boost overall R&D intensity (European Commission, 2014)

Results indicate that at the beginning of observed period Latvia was almost at the level of full efficiency (Figure 1). High level of efficiency Latvia maintain until 2004. After that strong decline in efficiency was recorded until 2015. Similar trend can be found in level of technology progress. Trends in efficiency and technology progress reflects on trends in productivity (Figure 2). At the end of the observed period, Latvia was on the same level of productivity as it was in 1999 (Figure 2). This goes in line with research of Łącka and Brzezicki (2021). Following the country’s EU accession, a noticeable decline in productivity coincided with significantly low levels of total R&D expenditure (Appendix, Figure A1-A3). From 2007 onward, foreign direct investment (FDI) began to fall, with only a brief recovery in 2015 (World Bank, 2025). During this period, foreign companies remained the primary drivers of business R&D spending, while overall investment remained limited. This shift led to higher education (HE) institutions becoming the dominant contributors to R&D expenditure, as business and government R&D spending reached nearly equal levels. Simultaneously, from 2007 to 2016, the number of R&D personnel declined (Appendix, Figure A4), largely due to demographic challenges and emigration of skilled professionals in science and technology (Šūpule, 2021). A slight improvement occurred in 2017 with the operational launch of the EU’s Horizon 2020 funding programme, which, along with other EU structural funds, partially offset national R&D budget cuts caused by the economic crisis. However, this also increased the country’s dependency on external financial resources (Klyvienė and Rasmussen, 2010).

Lithuania is another country that experienced a continuous decline in productivity throughout the entire observation period (Figure 2). While the overall trend was shaped by falling efficiency (Figure 1) and technological regression, the most significant drop occurred after 2009, when a sharp decline in efficiency further accelerated the downturn. As a result, by 2019, Lithuania’s productivity had fallen to just half of its 1999 level (Figure 2), marking one of the most severe deteriorations among the observed countries. These results confirm previous findings of Łącka and Brzezicki (2021). Throughout the entire observed period, higher education (HE) dominated Lithuania’s R&D expenditure (Appendix, Figure A1-A3). However, a decline began in 2017, which coincided with a noticeable drop in the number of scientific and technical publications. In recent years, growing foreign direct investment (FDI) has been accompanied by a slow but steady increase in business R&D spending, followed by a rise in patent activity. Most R&D activities are carried out by domestic companies such as Biotechpharma, Ekspla, Intechcentras, and the Open R&D network, while the largest foreign player, Thermo Fisher Scientific, entered the market in 2010. EU funds have played a crucial role in shaping Lithuania’s R&D landscape, primarily flowing through higher education and government channels.

The BCC model identifies the specific input and output adjustments required for an inefficient DMU to reach the efficient frontier within the given production possibility set. Figure 3 illustrates the percentage reductions in input variables for each country, as determined by the BCC model, necessary to achieve efficiency over the observed period.

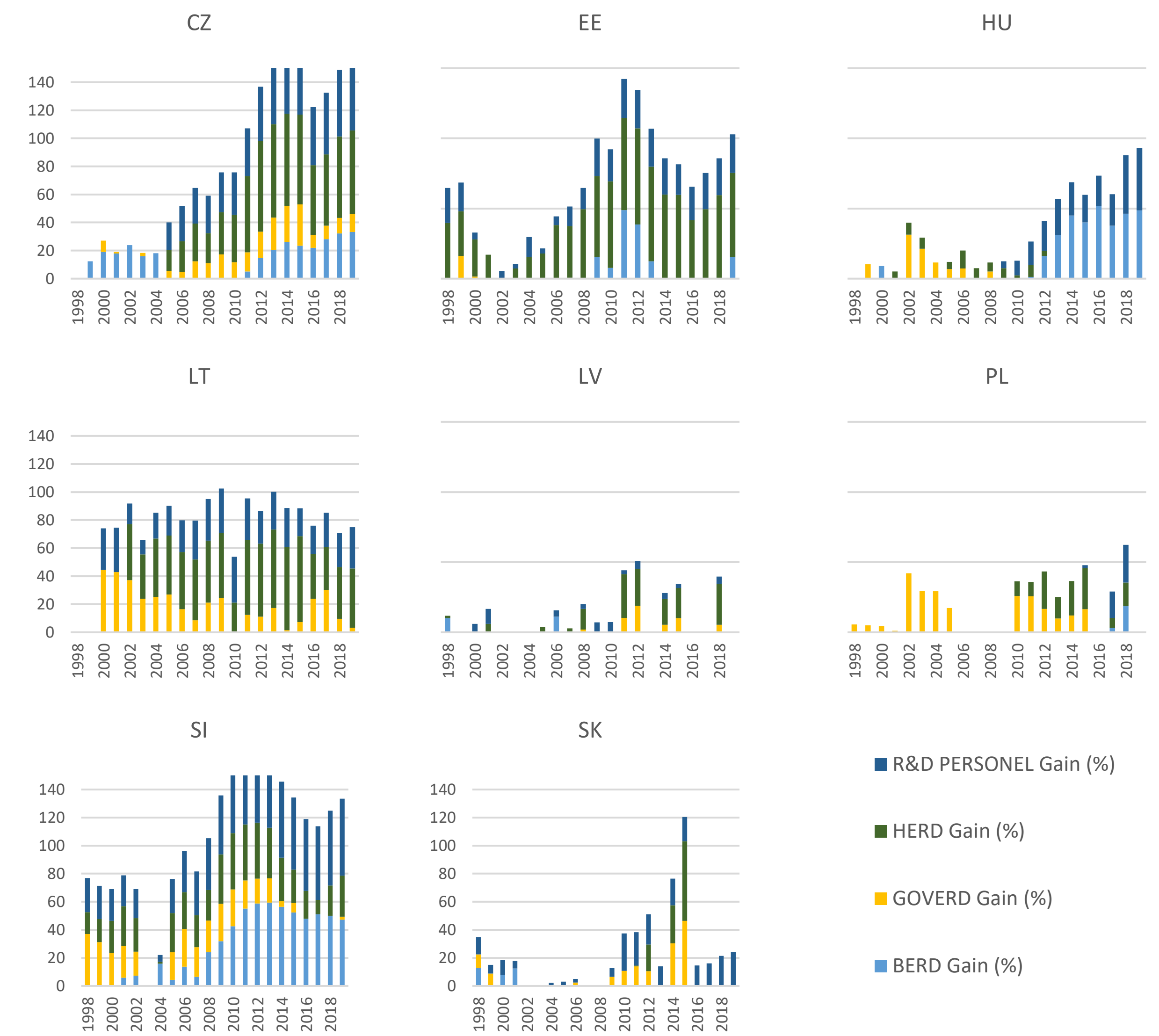

Figure 3. Input reductions (%) for each country obtained by BCC model

CEE countries inefficiency comes mostly from government and higher education sector poor allocation of R&D funds (Figure 3). These two sectors are strongly intervened since HE in CEE countries is predominantly public. Hence, this indicates on generally poor allocation of public R&D funds. All countries of CEE region indicate inefficiency in government and HE expenditure. Growing inefficiency in government and HE sector coincidence with increased availability of EU funds for public and educational programs. These findings make sense, since it is expected that this newly available funds will be used for institutional reorganization and reconstruction, and less for creation of indigenes innovation. However, trend shows that there is no much of improvement in government and HE efficiency even in a later year of observation (in many cases even going worse). Exposure to EU good practice and availability of R&D funds from EU didn't pollute with expected results. This indicates on unsuccessful utilization of funds and inadequate system transformation.

The transition to market economies in Central and Eastern Europe (CEE) was profoundly constrained by the absence of key institutional mechanisms—such as bankruptcy procedures and liquidation frameworks—essential for efficient market operation. Compounded by soft budget constraints and systemic inefficiencies, these economies lacked the foundational structures necessary to support a functional market-based financial system. As a result, the transformation of centrally planned economies into market-oriented models presented a significant challenge. Historically, CEE countries operated under state-led economic systems that heavily emphasized government-directed innovation, with minimal participation from the private sector. Nowhere was this more evident than in research and development (R&D), where public institutions controlled all stages—from fundamental research and design to engineering and problem-solving. Universities, state enterprises, and non-profit organizations often lacked the mechanisms to commercialize public research, discouraging innovation and aligning R&D priorities with state planning rather than market demand. This legacy entrenched a deep divide between scientific research and industrial application, prioritizing research outputs over practical innovation. Structural reforms—including shifts in R&D funding and large-scale privatization—disrupted this model, posing new challenges in constructing innovation systems compatible with market economies. These difficulties were exacerbated by the entry of foreign-owned R&D entities, which frequently displaced domestic innovation capabilities. The shift from state-controlled systems to market-driven frameworks demanded comprehensive reforms in fiscal policy, legal structures, and institutional design. This transformation was characterized by a fundamental tension between inherited socialist structures and the emerging demands of competitive, innovation-led economies. Building enterprise-level innovation capacity proved particularly difficult due to deeply embedded institutional hierarchies and rigidities, which created systemic misalignments and elevated transaction costs. Empirical evidence suggests that R&D conducted within the business sector is generally more productive than publicly funded research (Baran, 2023). Consequently, expanding domestic business R&D investment is widely viewed as a critical component for enabling a successful shift toward innovation-based economic growth in the region (Zavarská et al., 2024). In CEE countries, the private sector's higher productivity relative to public institutions can largely be attributed to stronger market incentives, competitive pressures (Mergele et al., 2025), and greater investments in advanced technologies. This dynamic underscore the importance of profit-driven motives in shaping effective innovation systems.

R&D personnel is another main generator of growing inefficiency in CEE countries, especially in Slovenia and Slovakia. This might come as a result of growing trend of non-research stuff among R&D personnel. Business sector also shows inefficiency, however, among all three sectors it is least inefficient. However, growing trend of business inefficiency is recorded in Hungary, Czech and Slovenia. Hungary is at the front of this set of countries. Reason for that could be found in limited domestic R&D capacity—especially the absence of innovative medium-sized firms—hampered the country's ability to fully absorb and build upon available foreign technologies.

However, there are other factors that play a crucial role in driving innovation, and which are not discussed in this paper—most notably, the strength and development of a country's entrepreneurship ecosystem. In Central and Eastern Europe (CEE), the evolution of entrepreneurship has been deeply shaped by the region's post-socialist transition since the early 1990s. Initially, entrepreneurship was often viewed with suspicion, frequently associated with opportunism and exploitation amid the chaotic aftermath of communism (Andonova et al., 2020). Over time, however, this perception shifted as a new generation of young, educated, and tech-oriented entrepreneurs emerged, gradually reframing entrepreneurship as a legitimate, aspirational, and innovation-driven pursuit (Fan et al., 2019). Despite this progress, significant challenges persist. The region's entrepreneurial ecosystems continue to face structural barriers such as limited collaboration among key stakeholders, overreliance on public funding, ongoing brain drain (Schmutzler et al., 2021), institutional instability, and corruption (Grigore & Dragan, 2020). Furthermore, the wholesale adoption of foreign legal frameworks—often transplanted without sufficient contextual adaptation—has resulted in enforcement challenges and interpretative ambiguities, especially in light of complex cultural and political transformations (Poček, 2016). Nevertheless, entrepreneurial activity has gained momentum across the region. Countries with less saturated markets have increasingly become hubs for experimentation, creativity, and startup activity (Hautala, 2015). The diaspora has also played a pivotal role, not only by connecting domestic ecosystems to global markets and resources but also by influencing evolving cultural attitudes toward entrepreneurship (Andonova et al., 2023). These dynamics highlight the limitations of applying conventional Western models of entrepreneurial ecosystems to the CEE context. Scholars have increasingly argued for more context-sensitive, longitudinal approaches that better reflect the region's transitional realities and complex institutional legacies (Chepurenko & Sauka, 2017). Understanding these unique conditions is essential for fostering sustainable, innovation-led entrepreneurship in the region.

6. CONCLUSION

Thirty years after transitioning to a market economy, Central and Eastern European (CEE) countries have not succeeded in closing the economic gap with the "old" EU member states (Cieślik and Wciślik, 2020). This persistent disparity is further exacerbated by a significant lag in innovation capacity (European Commission, 2024). Despite EU accession, increased R&D spending by domestic and foreign investors, and relatively stable institutional frameworks, these measures have not sufficed to generate sustained momentum in innovation activities. As Jindra et al (2015) observe, the technological capabilities of CEE countries remain insufficient to enable convergence with high-income economies. Weak industrial and innovation capacities have hindered the effective integration of domestic and foreign technologies and have raised the costs associated with acquiring new technologies (Radosevic, 2017). Moreover, the process of Europeanization, while expected to accelerate development, has instead intensified challenges from the 1990s and introduced new issues into the innovation policy landscape of the region. Chief among these are an overreliance on a linear model of innovation and an underdeveloped administrative infrastructure lacking the competencies required for strategic networking and long-term planning. The inflexibility of these systems and their disconnection from market signals have resulted in low value-added innovations, rendering the region less attractive for high value-added investments. Although a substantial innovation gap persists between CEE countries and the old EU members, some positive developments are evident. Estonia, Slovenia, and Poland have demonstrated the strongest productivity growth. Estonia and Poland, in particular, exhibit positive shifts of technological frontier and improvements in innovation system efficiency. Slovenia, while not showing frontier-shift, has made gains in efficiency. These improvements are largely attributed to the growth of the business sector, primarily financed by foreign capital, suggesting successful integration of foreign technology with domestic knowledge systems (Crandall and

Sulg, 2023). However, systemic inefficiencies within the public and higher education R&D sectors remain a critical challenge. Although EU funds were made available to support government and academic institutions, their potential impact was significantly undermined by the global financial crisis. Latvia and Slovakia have maintained productivity levels comparable to those of the late 1990s, while the Czech Republic, Hungary, and Lithuania have experienced a marked decline in innovation productivity. These latter countries have faced technological regression and reduced innovation system efficiency, indicating less successful systemic transformation and weaker development of innovation capacities. In these cases, the expanding business sectors failed to connect meaningfully with domestic knowledge resources. A common issue across all CEE countries is the pronounced inefficiency of public and higher education research sectors. This study contributes to the growing body of literature on innovation efficiency in CEE countries. While numerous prior studies have assessed the efficiency of R&D expenditures within underdeveloped institutional frameworks, this research takes a step further by decomposing R&D spending across three main sectors: government, business, and higher education. Differentiating between public (including higher education, which remains predominantly public in the CEE region) and private expenditure is crucial, as public investment is a legacy of the centrally planned economy, whereas private sector spending characterizes the market-oriented systems these countries have recently adopted. By incorporating a temporal dimension and analysing intertemporal productivity changes, this study captures the evolution of innovation capacity throughout the transition period, enabling the identification of distinct phases of economic and institutional transformation. From a policy perspective, the study provides insights that can support the design of more effective innovation strategies, helping to bridge gap between public, inefficient, and private, efficient, sector. Improving efficiency in the public and education sectors across CEE countries requires comprehensive structural reforms. Public administration should adopt redefined management models that prioritize performance measurement, transparency, and accountability. Introducing performance-based incentives could further enhance employee motivation. In the education sector, reforms should focus on aligning curricula with labor market demands, optimizing resource use, and embedding institutional performance evaluation into management practices. Additionally, knowledge and practices from the private sector—particularly in digitalization, HR management, and innovation—can inform improvements in public governance. Strengthening public-private partnerships (PPP) offers further potential for more efficient resource allocation and faster knowledge transfer, particularly in education, infrastructure, and digital services. However, the success of these reforms hinges on strong political will, institutional stability, and active involvement of civil society and international actors in policy evaluation and oversight. A key limitation of this research lies in the sample selection. Due to data unavailability, some CEE countries were excluded from the analysis. Future studies may address this gap by expanding the sample. Additionally, this study does not include the period from 1990 to 1999. Although significant changes during that time are unlikely due to systemic inertia, incorporating data from this period would offer a more comprehensive view of the region's transition to a market economy. Beyond expanding the time horizon, future research could also test the model in subsequent periods to assess the long-term sustainability of observed innovation trends.

CONFLICT OF INTEREST

Authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

REFERENCES

Andonova, V., Perez-Lopez, J. A., and Schmutzler, J. (2019) 'The role of diaspora in entrepreneurial ecosystems and national innovation systems', in Tsvetkova, A., Pugh, Rh., and Schmutzler, J. (eds.) Entrepreneurial ecosystems meet innovation systems, Cheltenham: Edward Elgar Publishing, pp. 61–83.

Andonova, V., Gavrilova, S., Pérez, J., Schmutzler, J., and Kristeff, M. (2023) 'Bulgaria: The relevance and impact of transnational diaspora in technology-driven entrepreneurship', in Sternberg, R., Elo, M., Levie, J., and Amorós, E. (eds.) Research handbook on transnational diaspora entrepreneurship, Cheltenham: Edward Elgar Publishing, pp. 86–108.

Åslund, A. (2013) How capitalism was built: The transformation of Central and Eastern Europe, Russia, the Caucasus, and Central Asia. Cambridge: Cambridge University Press.

Bahl, M., Lahiri, S., and Mukherjee, D. (2021) 'Managing internationalization and innovation tradeoffs in entrepreneurial firms: Evidence from transition economies', Journal of World Business, 56(1), p. 101150. Available at: https://doi.org/10.1016/j.jwb.2020.101150.

Baran, K. (2023) 'The determinants of economic growth in Hungary, Poland, Slovakia and the Czech Republic since the transition'.

Bielicki, M., and Leśniak, M. (2016) 'CEE cross-country comparison of national innovation systems efficiency: DEA approach', in Proceedings of the 11th European Conference on Innovation and Entrepreneurship, pp. 87. Available at: https://bazawiedzy.ue.poznan.pl/info/article/UEP8609889a73194837b0b2d5f3a26342a4.

Braha, K., Qineti, A., and Serenčéš, R. (2015) 'Innovation and economic growth: The case of Slovakia', Visegrad Journal on Bioeconomy and Sustainable Development, 4(1), pp. 7–13. Available at: https://doi.org/10.1515/vjbsd-2015-0002.

Broekel, T., Rogge, N., and Brenner, T. (2018) 'The innovation efficiency of German regions – a shared-input DEA approach', Review of Regional Research, 38, pp. 77–109. Available at: https://doi.org/10.1007/s10037-017-0112-0.

Cai, Y., and Hanley, A. (2014) 'Innovation rankings: Good, bad or revealing?', Applied Economics Letters, 21(5), pp. 325–328. Available at: https://doi.org/10.1080/13504851.2013.859366.

Carayannis, E. G., Grigoroudis, E., and Goletsis, Y. (2016) 'A multilevel and multistage efficiency evaluation of innovation systems: A multiobjective DEA approach', Expert Systems with Applications, 62, pp. 63–80. Available at: https://doi.org/10.1016/j.eswa.2016.06.017.

Cavallaro, E., and Villani, I. (2021) 'Club convergence in EU countries', Journal of Economic Integration, 36(1), pp. 125–161. Available at: https://doi.org/10.11130/jei.2021.36.1.125.

Chen, K., and Guan, J. (2012) 'Measuring the efficiency of China's regional innovation systems: Application of network data envelopment analysis (DEA)', Regional Studies, 46(3), pp. 355–377. Available at: https://doi.org/10.1080/00343404.2010.497479.

Chen, Y., Cook, W. D., Kao, C., and Zhu, J. (2014) 'Network DEA pitfalls: Divisional efficiency and frontier projection', in Cook, W. D., and Zhu, J. (eds.) Data envelopment analysis: A handbook on the modeling of internal structures and networks, Boston, MA: Springer US, pp. 31–54. Available at: https://link.springer.com/chapter/10.1007/978-1-4419-6151-8_2.

Chepurenko, A., and Sauka, A. (2017) 'Introduction: Systematic "transition" and entrepreneurship theory', in Sauka, A., and Chepurenko, A. (eds.) Entrepreneurship in transition economies. Societies and political orders in transition, Cham: Springer. Available at: https://doi.org/10.1007/978-3-319-57342-7_1.

Cieślik, A., and Wciślik, D. R. (2020) 'Convergence among the CEE-8 economies and their catch-up towards the EU-15', Structural Change and Economic Dynamics, 55, pp. 39–48. Available at: https://doi.org/10.1016/j.strueco.2020.07.006.

Ciocoiu, C. N., Cioc, M., Marinescu, C., Baciu, S. G., and Sadkowska, J. (2025) 'Performance analysis in tourism: Romania's competitiveness among Central and Eastern European countries', Sustainability, 17(4), p. 1697. Available at: https://doi.org/10.3390/su17041697.

Ciołek, D., and Golejewska, A. (2022) 'Efficiency determinants of regional innovation systems in Polish subregions', Gospodarka Narodowa. The Polish Journal of Economics, 311(3), pp. 24–45. Available at: https://doi.org/10.33119/GN/151792.

Cooper, W. W., Seiford, L. M., and Zhu, J. (2011) 'Data envelopment analysis: History, models, and interpretations', in Cooper, W. W., Seiford, L. M., and Zhu, J. (eds.) Handbook on data envelopment analysis, Springer US, pp. 1–39. Available at: http://dx.doi.org/10.1007/978-1-4419-6151-8_1.

Crandall, M., and Sulg, M. L. (2023) 'Small states and new status opportunities: Estonia's foreign policy towards Africa', European Politics and Society, 24(2), pp. 250–264. Available at: https://www.tandfonline.com/doi/abs/10.1080/23745118.2021.1990662.

Dobrzanski, P. (2018) 'Innovation expenditures efficiency in Central and Eastern European countries', Zbornik Radova Ekonomskog Fakulteta u Rijeci, 36(2), pp. 827–859. Available at: https://doi.org/10.18045/zbefri.2018.2.827.

Dzemydaitė, G., Dzemyda, I., and Galinienė, B. (2016) 'The efficiency of regional innovation systems in new member states of the European Union: A nonparametric DEA approach', Economics and Business, 28, pp. 83–89. Available at: https://doi.org/10.1515/eb-2016-0012.

Eapen, A., Yeo, J., and Sasidharan, S. (2019) 'Finance constraints and technology spillovers from foreign to domestic firms', Economic Modelling, 76, pp. 50–62. Available at: https://doi.org/10.1016/j.econmod.2018.07.019.

European Commission (2024) European innovation scoreboard 2024. Projects Research and Innovation. Available at: https://projects.research-and-innovation.ec.europa.eu/en/statistics/performance-indicators/european-innovation-scoreboard/eis-2024#/eis.

Fan, P., Urs, N., and Hamlin, R. E. (2019) ‘Rising innovative city-regions in a transitional economy: A case study of ICT industry in Cluj-Napoca, Romania’, Technology in Society, 58, p. 101139.

Färe, R., Grosskopf, S., Norris, M., and Zhang, Z. (1994) ‘Productivity growth, technical progress, and efficiency change in industrialized countries’, American Economic Review, 84(1), pp. 66–83. Available at: https://www.jstor.org/stable/2117971.

Firsova, A., and Chernyshova, G. (2020) ‘Efficiency analysis of regional innovation development based on DEA Malmquist index’, Information, 11(6), p. 294. Available at: https://doi.org/10.3390/info11060294.

Foreman-Peck, J., and Zhou, P. (2022) ‘R&D subsidies and productivity in eastern European countries’, Economic Systems, 46(2), p. 100978. Available at: https://doi.org/10.1016/j.ecosys.2022.100978.

Freeman, S., and Reid, I. (2006) ‘Constraints facing small western firms in transitional markets’, European Business Review, 18(3), pp. 187–213. Available at: https://doi.org/10.1108/09555340610663728.

Gomułka, S. (2023) Global long-term economic growth and the economic transformation of Poland and Eastern Europe. Wydawnictwo Naukowe Scholar Sp. z o.o.

Granstrand, O., and Holgersson, M. (2020) ‘Innovation ecosystems: A conceptual review and a new definition’, Technovation, 90, p. 102098. Available at: https://doi.org/10.1016/j.technovation.2019.102098.

Grigore, A. M., and Dragan, I. M. (2020) ‘Towards sustainable entrepreneurial ecosystems in a transitional economy: An analysis of two Romanian city-regions through the lens of entrepreneurs’, Sustainability, 12(15), p. 6061. Available at: https://doi.org/10.3390/su12156061.

Grifell-Tatjé, E., and Lovell, C. A. K. (1995) ‘A note on the Malmquist productivity index’, Economics Letters, 47(2), pp. 169–175. Available at: https://doi.org/10.1016/0165-1765(94)00497-P.

Grosu, A. C., Pintilescu, C., and Zugravu, B. (2022) ‘Trends in public debt sustainability in Central and Eastern EU countries’, Post-Communist Economies, 34(2), pp. 173–195. Available at: https://doi.org/10.1080/14631377.2020.1867431.

Guan, J., and Chen, K. (2010) ‘Measuring the innovation production process: A cross-region empirical study of China’s high-tech innovations’, Technovation, 30(5–6), pp. 348–358. Available at: https://doi.org/10.1016/j.technovation.2010.02.001.

Hartsenko, J., and Sauga, A. (2012) ‘Does financial support from the EU structural funds have an impact on the firms’ performance: Evidence from Estonia’, in Proceedings of 30th International Conference Mathematical Methods in Economics, Karvina: School of Business Administration, Silesian University, pp. 260–265.

Hautala, J. (2015) ‘Interaction in the artistic knowledge creation process: The case of artists in Finnish Lapland’, Geoforum, 65, pp. 351–362.

Ireland, R. D., Tihanyi, L., and Webb, J. W. (2008) ‘A tale of two politico-economic systems: Implications for entrepreneurship in Central and Eastern Europe’, Entrepreneurship Theory and Practice, 32(1), pp. 107–130. Available at: https://doi.org/10.1111/j.1540-6520.2007.00218.x.

Jindra, B., Lacasa, I. D., and Radosevic, S. (2015) ‘Dynamics of technology upgrading of the Central and East European countries in a comparative perspective: Analysis based on patent data’, Economics and Business Working Paper, 44(135), pp. 1–42.

Jurickova, E., Bobak, R., Pilik, M., and Hrusecka, D. (2017) ‘Efficiency of innovation system in the Czech Republic: Comparison with other European countries’, New Trends and Issues Proceedings on Humanities and Social Sciences, 4(10), pp. 90–96. Available at: https://doi.org/10.18844/prosoc.v4i10.3066.

Kadlec, V., and Blažek, J. (2015) ‘University-business collaboration as perceived by leading academics: Comparing and contrasting the two most innovative Czech regions’, Erdkunde, 69(4), pp. 327–339. Available at: https://www.jstor.org/stable/24585781.

Kirankabeş, M. C., and Erkul, A. (2019) ‘Regional knowledge production in Central and East European countries: R&D factor productivity and changes in performances’, Eastern Journal of European Studies, 10(1), pp. 25–44. Available at: https://ideas.repec.org/a/jes/journl/y2019v10p25-44.htmlIDEAS/RePEc.

Kirikal, L., Sõrg, M., and Vensel, V. (2004) ‘Estonian banking sector performance analysis using Malmquist indexes and DuPont financial ratio analysis’, International Business & Economics Research Journal, 3(12), pp. 21–36. Available at: http://dx.doi.org/10.19030/iber.v3i12.3746

Klingebiel, R., and Rammer, C. (2014) ‘Resource allocation strategy for innovation portfolio management’, Strategic Management Journal, 35(2), pp. 246–268. Available at: https://doi.org/10.1002/smj.2107.

Klyvienė, V., and Rasmussen, L. T. (2010) ‘Causes of financial crisis: The case of Latvia’, Ekonomika, 89(2), pp. 7–27. Available at: https://doi.org/10.15388/Ekon.2010.0.988.

Kornai, J. (1998) From Socialism to Capitalism: What is meant by the ‘change of system’? Social Market Foundation, Centre for Post-Collectivist Studies.

Kravtsova, V., and Radosevic, S. (2012) ‘Are systems of innovation in Eastern Europe efficient?’, Economic Systems, 36(1), pp. 109–126. Available at: https://doi.org/10.1016/j.ecosys.2011.04.005.

Kriaucioniene, M., and Ragauskas, A. (2008) ‘Transition via R&D: Emerging forms and strategies of corporate R&D in the catch-up countries (Lithuanian case)’, in IV Globelics Conference at Mexico City, September, pp. 22–24.

Lacasa, I. D., Giebler, A., and Radosevic, S. (2017) ‘Technological capabilities in Central and Eastern Europe: An analysis based on priority patents’, Scientometrics, 111(1), pp. 83–102. Available at: https://doi.org/10.1007/s11192-017-2277-2.

Łącka, I., and Brzezicki, Ł. (2021) ‘The efficiency and productivity evaluation of national innovation systems in Europe’, European Research Studies, 24, pp. 471–496. Available at: http://dx.doi.org/10.2139/ssrn.3922778.

Lewis, C., and Fall, F. (2017) ‘Enhancing public sector efficiency and effectiveness in the Czech Republic’, OECD Economics Department Working Papers, No. 1363. OECD Publishing. Available at: https://doi.org/10.1787/37ac46c4-en.

Lundvall, B. Å. (2024) ‘Transformative innovation policy–lessons from the innovation system literature’, Innovation and Development, 14(2), pp. 297–314. Available at: https://doi.org/10.1080/2157930X.2023.2234567.

Lundvall, B. Å., Dosi, G., and Freeman, C. (1988) ‘Innovation as an interactive process: From user-producer interaction to the national system of innovation’, in G. Dosi et al. (eds.) Technical Change and Economic Theory, pp. 349–369. Pinter Publishers. Available at: https://www.worldcat.org/title/technical-change-and-economic-theory/oclc/18782488.

Magnusson, L., and Ottosson, J. (1997) Evolutionary economics and path dependence. Edward Elgar Publishing. Available at: https://econpapers.repec.org/bookchap/elgeebook/896.htm.

Magyar Nemzeti Bank (2023) Competitiveness Report 2023. Available at: https://www.mnb.hu/en/publications/reports/competitiveness-report.

Mandel, E. (1986) ‘In defence of socialist planning’, New Left Review, 159(1), pp. 5–22. Available at: http://digamo.free.fr/mandelsp.pdf.

Martin, S., Pahor, M., and Jaklič, M. (2015) ‘The structure of policy-induced innovation networks in Slovenia’, European Journal of Innovation Management, 18(4), pp. 428–450. Available at: https://doi.org/10.1108/EJIM-06-2014-0061.

Masso, J., and Tiwari, A. K. (2024) ‘Productivity impacts of R&D and non-R&D modes of technological change for incumbents and entrants in a catching-up economy’, Technological Forecasting and Social Change, 199, 123015. Available at: https://doi.org/10.1016/j.techfore.2023.123015.

Masso, J., and Vahter, P. (2008) ‘Technological innovation and productivity in late-transition Estonia: Econometric evidence from innovation surveys’, The European Journal of Development Research, 20(2), pp. 240–261. Available at: https://doi.org/10.1080/09578810802060798.

McMillan, J., and Naughton, B. (1992) ‘How to reform a planned economy: Lessons from China’, Oxford Review of Economic Policy, 8(1), pp. 130–143. Available at: https://doi.org/10.1093/oxrep/8.1.130.

Mensah, E. B., Owusu, S., and Foster-McGregor, N. (2023) ‘Productive efficiency, structural change, and catch-up within Africa’, Structural Change and Economic Dynamics, 65, pp. 78–100. Available at: https://doi.org/10.1016/j.strueco.2023.04.001.

Mergele, L., Hennicke, M., and Lubczyk, M. (2025) ‘The big sell: Privatizing East Germany’s economy’, Journal of Public Economics, 242, 105291.

Misztal, P. (2020) ‘Foreign direct investment, production factors productivity and income inequalities in selected CEE countries’, TalTech Journal of European Studies, 10(1), pp. 146–172. Available at: https://doi.org/10.1515/bjes-2020-0009.

Mitu, N. E., and Stanciu, C. V. (2023) ‘Public sector performance and public sector efficiency: An analysis for CEE countries’, Eastern European Economics, 61(6), pp. 700–722. Available at: https://doi.org/10.1080/00128775.2023.2211234.

Morvay, K., Frank, K., Hudcovský, M., Hvozdíková, V., Jeck, T., Lichner, I., et al. (2021) Economic Development of Slovakia in 2020. Bratislava: Institute of Economic Research of Slovak Academy of Sciences. e-ISBN: 978–80–7144–337–7.

Ndicu, S., Ngui, D., and Barasa, L. (2024) ‘Technological catch-up, innovation, and productivity analysis of national innovation systems in developing countries in Africa 2010–2018’, Journal of the Knowledge Economy, 15(2), pp. 7941–7967. Available at: https://doi.org/10.1007/s13132-023-01123-5.

Niosi, J. (2002) ‘National systems of innovations are “x-efficient” (and x-effective): Why some are slow learners’, Research Policy, 31(2), pp. 291–302. Available at: https://doi.org/10.1016/S0048-7333(01)00138-4.

Nistor, C. S., and Deaconu, A. (2012) ‘The link between human resources competitiveness and Romanian academic education’, Procedia Economics and Finance, 3, pp. 806–816. Available at: https://doi.org/10.1016/S2212-5671(12)00232-0.

Nooteboom, B. (2000) ‘Institutions and forms of coordination in innovation systems’, Organization Studies, 21(5), pp. 915–939. Available at: https://doi.org/10.1177/0170840600215001.

Nye, A. (2021) ‘Bank assets management company (BAMC)’, Journal of Financial Crises, 3(2), pp. 665–725. Available at: https://elischolar.library.yale.edu/journal-of-financial-crises/vol3/iss2/4/.

OECD (2015) Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities. OECD Publishing, Paris. Available at: https://doi.org/10.1787/9789264239012-en.

OECD (2004) OECD Economic Surveys: Hungary 2004. OECD Publishing, Paris. Available at: https://doi.org/10.1787/eco_surveys-hun-2004-en.

OECD (2024) R&D personnel. OECD.Stat. Available at: https://stats.oecd.org/.

Perényi, Á., Esposto, A., and Bamforth, J. (2020) 'Institutional transformation and development from an economic transition perspective: The case of Argentina', Journal of Institutional Economics, 16(1), pp. 83–104. Available at: https://doi.org/10.1017/S1744137419000194.

Petrariu, I. R., Bumbac, R., and Ciobanu, R. (2013) 'Innovation: A path to competitiveness and economic growth. The case of CEE countries', Theoretical & Applied Economics, 20(5), pp. 15–26.

Popescu, G. H. (2014) 'FDI and economic growth in Central and Eastern Europe', Sustainability, 6(11), pp. 8149–8163. Available at: https://doi.org/10.3390/su6118149.

Portela, M. C. A. S., and Thanassoulis, E. (2010) 'Malmquist indices for measuring productivity in the presence of negative data: An application to bank branches', Journal of Banking & Finance, 34(7), pp. 1472–1483. Available at: https://doi.org/10.1016/j.jbankfin.2010.01.004.

Poček, J. (2016) The political and legal phenomenon of legal transplants in labour law with a focus on employment relationship [Doctoral thesis]. UNIMI, Milano, Italy.

Prokop, V., Stejskal, J., Klimova, V., and Zitek, V. (2021) 'The role of foreign technologies and R&D in innovation processes within catching-up CEE countries', PLOS ONE, 16(4), e0250307. Available at: https://doi.org/10.1371/journal.pone.0250307.

Radosevic, S. (1999) 'Transformation of science and technology systems into systems of innovation in central and eastern Europe: the emerging patterns and determinants', Structural Change and Economic Dynamics, 10(3–4), pp. 277–320. Available at: https://doi.org/10.1016/S0954-349X(99)00016-8.

Radosevic, S. (2017a) 'Assessing EU smart specialization policy in a comparative perspective', in Advances in the Theory and Practice of Smart Specialization, pp. 1–36. Academic Press. Available at: https://doi.org/10.1016/B978-0-12-804137-6.00001-2.

Radosevic, S. (2017b) 'Upgrading technology in Central and Eastern European economies', IZA World of Labor, 338. Available at: http://doi.org/10.15185/izawol.338.

Radosevic, S. (2022) 'Techno-economic transformation in Eastern Europe and the former Soviet Union–A neo-Schumpeterian perspective', Research Policy, 51(1), 104397. Available at: https://doi.org/10.1016/j.respol.2021.104397.

Radosevic, S., and Yoruk, E. (2018) 'Technology upgrading of middle income economies: A new approach and results', Technological Forecasting and Social Change, 129, pp. 56–75. Available at: https://doi.org/10.1016/j.techfore.2017.12.002.

Rosenberg, N. (1994) Exploring the Black Box: Technology, Economics, and History. Cambridge University Press.

Schmutzler, J., Andonova, V., and Perez-Lopez, J. (2021) 'The role of diaspora in opportunity-driven entrepreneurial ecosystems: A mixed-methods study of Balkan economies', International Entrepreneurship and Management Journal, 17(2), pp. 693–729.

Section for the Science, Research and Innovation (2016) National Research, Development and Innovation Policy of the Czech Republic 2016–2020. Office of the Government of the Czech Republic. Available at: http://www.czech-research.com/rd-system/key-documents/national-research-development-and-innovation-policy-of-the-czech-republic-2016-2020/

Sekuloska, J. D. (2014) 'Higher education and training as crucial pillars in creating the competitiveness of nation', Procedia - Social and Behavioral Sciences, 156, pp. 241–246. Available at: https://doi.org/10.1016/j.sbspro.2014.11.182.

Sila, U., Morgavi, H., and Dall'Orso, J. (2017) 'Trends in productivity and sources of productivity growth in Slovenia', OECD Economics Department Working Papers, No. 1368. OECD Publishing, Paris. Available at: http://dx.doi.org/10.1787/a6691907-en.

Statistics Estonia (2013) 'Last year the expenditures on research and development activities remained at the level of 2011', News Release, No. 145. Available at: https://stat.ee/en/uudised/news-release-2013-145.

Šūpule, I. (2021) 'Intentions to stay or to return among highly skilled Latvians in the EU: Who is more likely to return?', Journal of Baltic Studies, 52(4), pp. 547–563. Available at: https://doi.org/10.1080/01629778.2021.1936583.

Thomas, V. J., Jain, S. K., and Sharma, S. (2009) 'Analyzing R&D efficiency in Asia and the OECD: An application of the Malmquist productivity index', in 2009 Atlanta Conference on Science and Innovation Policy, pp. 1–10. IEEE. Available at: http://doi.org/10.1109/ACSIP.2009.5367816.

van Ark, B., and Inklaar, R. (2006) 'Catching up or getting stuck? Europe's troubles to exploit ICT's productivity potential', GGDC Research Memorandum GD-79, University of Groningen.

Vokoun, M., and Dvouletý, O. (2025) 'International, national and sectoral determinants of innovation: Evolutionary perspective from the Czech, German, Hungarian and Slovak community innovation survey data', Innovation: The European Journal of Social Science Research, 38(1), pp. 495–535. Available at: https://doi.org/10.1080/13511610.2022.2158309.

World Bank (2025) 'Foreign direct investment, net inflows (BoP, current US$)'. Available at: https://data.worldbank.org/indicator/BX.KLT.DINV.CD.WD.

Yeravdekar, V. R., and Tiwari, G. (2014) 'China's lead in higher education: Much to learn for India', Procedia - Social and Behavioral Sciences, 157, pp. 369–372. Available at: https://doi.org/10.1016/j.sbspro.2014.11.041.

Yesilay, R. B., and Halac, U. (2020) 'An assessment of innovation efficiency in EECA countries using the DEA method', in Contemporary Issues in Business Economics and Finance, pp. 203–215. Emerald Publishing Limited. Available at: https://doi.org/10.1108/S1569-375920200000104014.

You, Z., and Teirlinck, P. (2024) ‘Heterogeneous influences of specialization and diversification on regional R&D performance: A China, Europe, and US comparison’, Science and Public Policy, 51(6), pp. 1169–1184. Available at: https://doi.org/10.1093/scipol/scae059.

Zabala-Iturriagagoitia, J. M., Aparicio, J., Ortiz, L., Carayannis, E. G., and Grigoroudis, E. (2021) ‘The productivity of national innovation systems in Europe: Catching up or falling behind?’, Technovation, 102, 102215. Available at: https://doi.org/10.1016/j.technovation.2020.102215.

Zavarská, Z., Bykova, A., Grieveson, R., and Guadagno, F. (2024) Toward innovation-driven growth: Innovation systems and policies in EU member states of Central Eastern Europe (No. 476). wiiw Research Report.

Zemtsov, S., and Kotsemir, M. (2019) ‘An assessment of regional innovation system efficiency in Russia: The application of the DEA approach’, Scientometrics, 120(2), pp. 375–404. Available at: https://doi.org/10.1007/s11192-019-03130-y.

APPENDIX

Figures A1-A6 show values of each input and output variable in each country in the period of 1998-2019.

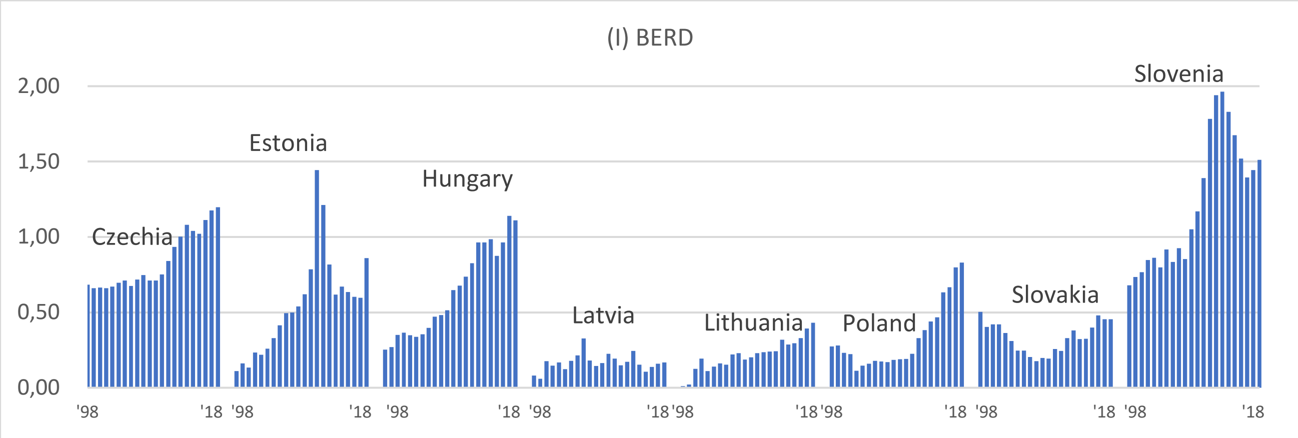

Figure A1. Business expenditures in R&D (%GDP) (Source: OECD: 2024, https://data-explorer.oecd.org/)

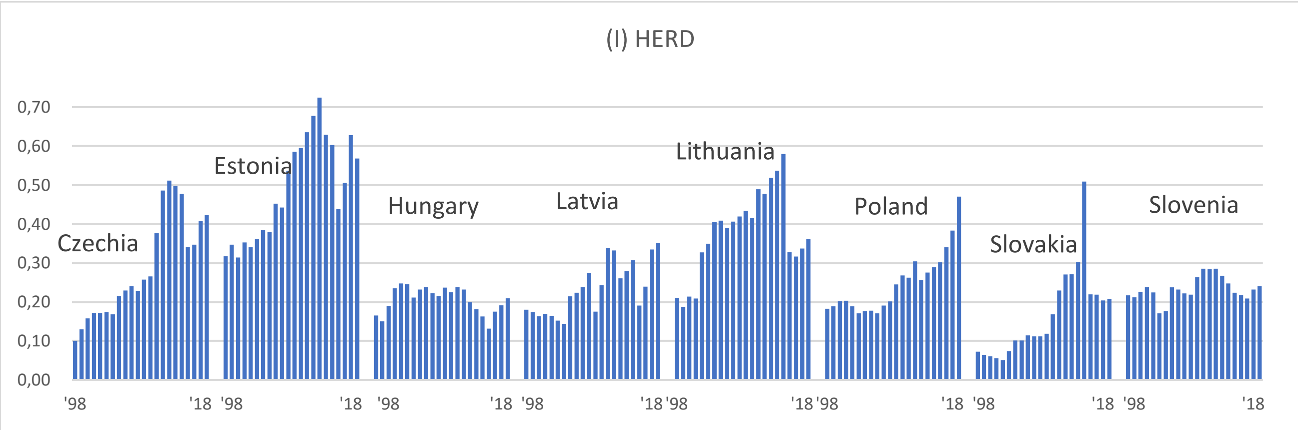

Figure A2. Higher-education expenditure on R&D (%GDP) (Source: OECD: 2024, https://data-explorer.oecd.org/)

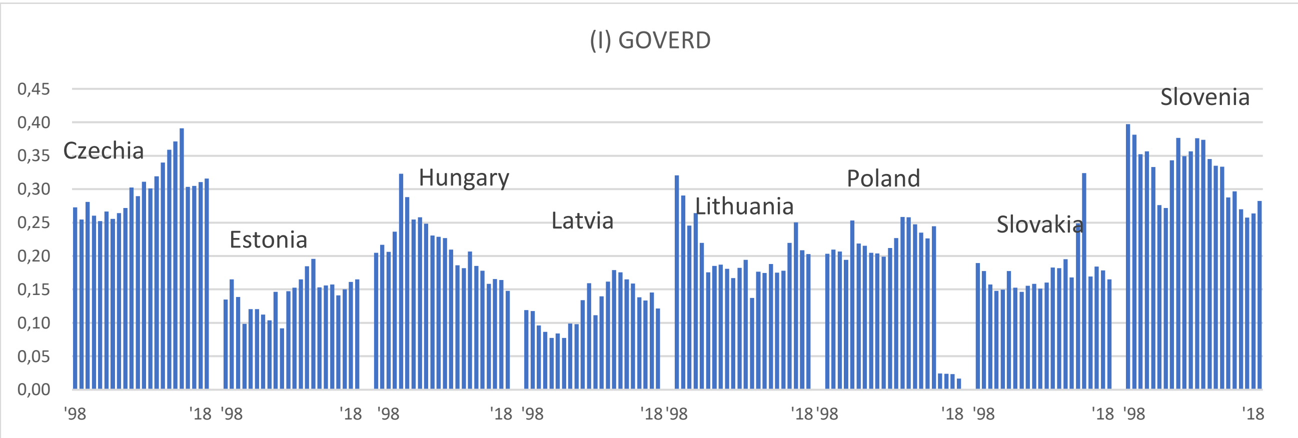

Figure A3. Government expenditures in R&D (%GDP) (Source: OECD: 2024, https://data-explorer.oecd.org/)

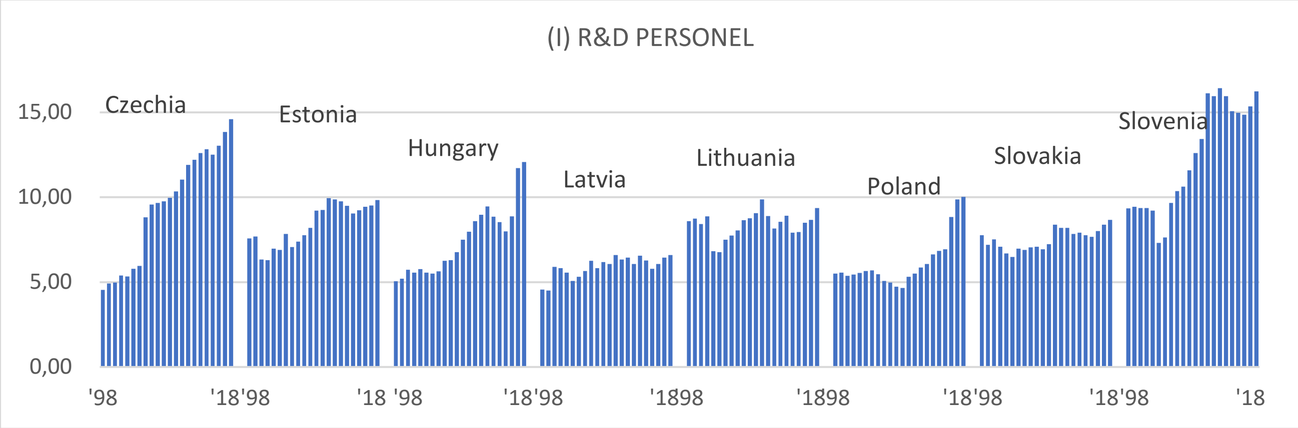

Figure A4. R&D personnel (%GDP) (Source: OECD: 2024, https://data-explorer.oecd.org/)

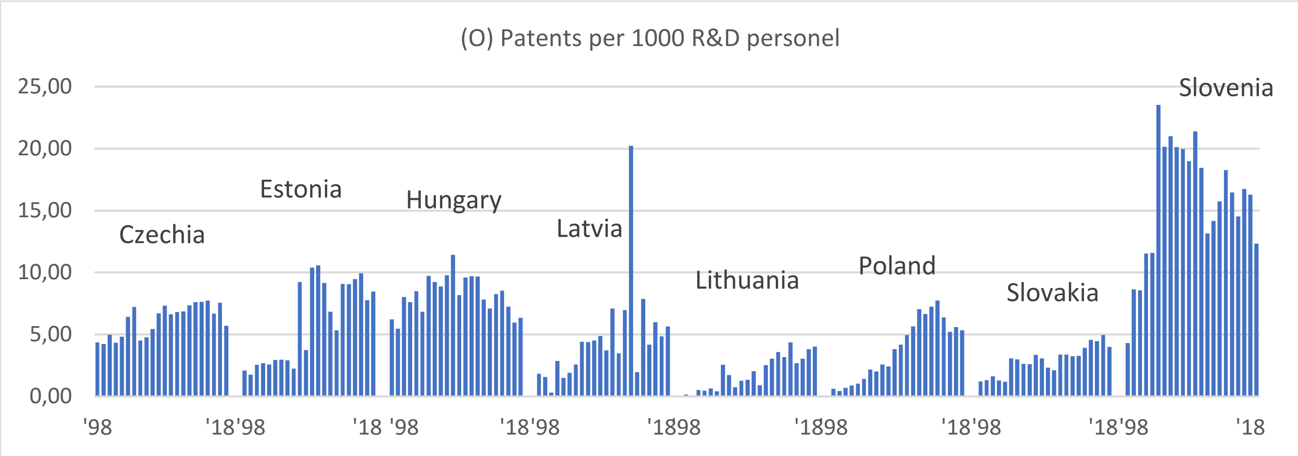

Figure A5. Patents per 1000 R&D personnel (Source: OECD: 2024, https://data-explorer.oecd.org/)

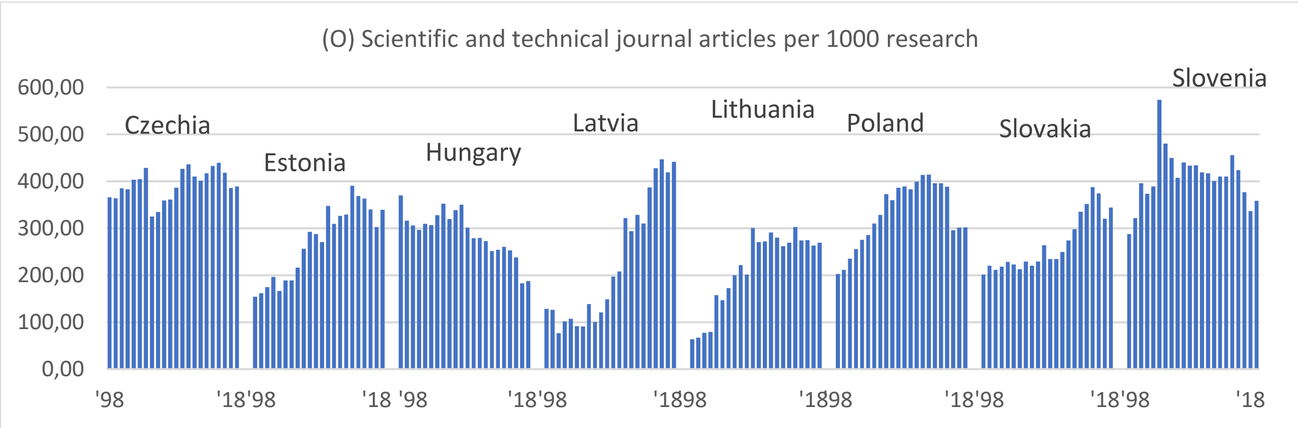

Figure A6. The number of scientific and technical journal articles per 1000 R&D personnel (Source: OECD: 2024, https://data-explorer.oecd.org/)