

## Determinants of Total Factor Productivity in the EU-CEE. The Role of Intangible Assets and Institutional Quality



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**Abstract:** This study investigates the determinants of total factor productivity (TFP) in European Union (EU) countries, with a particular focus on the transition economies of Central and Eastern Europe (EU-CEE). Using a balanced panel dataset for 2013-2019, we apply fixed-effects panel regression with robust standard errors to assess the impact of four key factors: intangible asset accumulation, business environment quality, information and communication technologies (ICTs), and knowledge workers on TFP growth. The results demonstrate that investment in intangible assets has a consistent and statistically significant positive effect on TFP across all model specifications. The quality of the business environment also significantly influences productivity, especially in EU-CEE countries, where institutional reforms and regulatory improvements have delayed but lasting effects. ICTs contribute positively to TFP, with a stronger lagged impact in countries where digital infrastructure and absorption capacity are still developing. Conversely, the share of knowledge workers does not show a statistically significant relationship with productivity unless complemented by investments in intangible and organizational capital. The findings confirm that intangible assets and institutional quality are decisive long-term drivers of productivity growth and convergence in the EU. The policy implications highlight the need for sustained support for intangible investment, ICT diffusion, and institutional strengthening to accelerate productivity and narrow regional disparities.

**Keywords:** intangible assets; innovation; total factor productivity.

**JEL Classification:** E23; O33; C23; O40; O34.

### Introduction

Total factor productivity (TFP) is widely regarded as a core indicator of long-run economic growth. Since Solow's seminal contribution, which attributed most growth to technological progress rather than mere factor accumulation (Solow, 1957), the debate has evolved through the endogenous growth literature, which shows that technological change is itself the outcome of purposeful investment, especially in research and development (Romer, 1990; Aghion and Howitt, 1992). Conceptually, TFP captures the efficiency with which economies transform available inputs into outputs raising production without proportionate increases in labor or capital (van Beveren, 2012). In practice, sustained TFP growth is typically associated with technological progress, innovation, organizational change, institutional quality, and a supportive business environment (Gu and Tang, 2004; Masso and Vahter, 2012; Cortinovis and van Oort, 2018). The cumulative effect of these forces underpins the transition toward a knowledge economy, in which value added relies less on tangible inputs and more on intangibles such as innovation capacity and intangible assets. Innovation and TFP are closely linked. Innovation tends to increase TFP, yet its effectiveness depends on complementary conditions including the institutional framework and the stock of intangible assets (Corrado *et al.* 2009). Higher productivity, in turn, relaxes resource constraints and enables further investment in innovation, creating a reinforcing dynamic that warrants careful empirical evaluation.

Despite an extensive body of literature on the determinants of TFP, empirical evidence on how intangible assets, ICT, and institutional quality shape TFP in EU countries remains incomplete. Existing research concentrates mostly on advanced EU-15 economies, whereas the mechanisms driving productivity in EU-CEE countries shaped by structural aspects that are still insufficiently explored. EU-CEE possess less mature innovation systems, lower historical levels of intangible capital, and more volatile institutional environments. Their productivity growth is driven mainly by technology adoption rather than frontier innovation and is constrained by weaker absorptive capacity and regulatory quality. This study addresses this gap by comparing model specifications for EU-CEE economies and by integrating composite indicators of innovation, business environment quality, and human capital into a unified TFP framework. Based on this identified gap in the literature, we prepare research questions and hypothesis presented in method section.

Romer (1990) formalizes how technological advances shift the production possibility frontier, enabling greater output from the same inputs, whereas knowledge spillovers diffuse benefits beyond their originators (Griliches, 1998). Intangible assets including those related to digitization and ICT improve managerial efficiency and open new production possibilities (Corrado *et al.* 2009; Wang *et al.* 2024). Innovation also fosters more efficient resource allocation by directing labor and capital toward higher productivity uses, with spillover effects at broader spatial scales (Cortinovis and van Oort, 2018). Critically, the returns to innovation depend on the quality of the regulatory and institutional environment, where rules are predictable and enforcement credible, investments in new technologies are more likely to translate into TFP gains (North, 1990). Thus, the presence of innovation alone does not guarantee higher productivity, the economic and legal contexts in which innovation occurs are decisive for its impact on TFP.

The impact of innovation on TFP growth is not homogeneous. Cortinovis and van Oort (2018) demonstrated that the regional context and the RandD environment influence the relationship between innovation and productivity. Their analysis of EU-15 and EU-CEE countries revealed that, in Western Europe, the dominant driver of TFP is the interaction between intangible assets and innovation, whereas in Central and Eastern Europe, the decisive factors are the quality of the regulatory and business environment and the absorptive capacity of firms to adopt modern technologies. As shown by Wang *et al.* (2020), sectoral and regional characteristics imply that the effects of investment in research and development vary according to the level of regional development. The more advanced the economy is, the faster it can transform such investments into productivity gains. Conversely, less developed economies face barriers such as a weaker business environment and a lower ability to absorb new technologies. It is therefore essential to analyse the impact of innovation on TFP at the regional level, taking into account the quality of the business environment.

The relationship between innovation and TFP is not linear or isolated. Rather, it is shaped by interconnections and synergies among complementary factors. Moreover, the accumulation of intangible assets one of the key prerequisites for generating new innovations poses methodological challenges. While tangible capital is easily captured in accounting frameworks, intangible assets are more difficult to quantify and report. Underestimating the accumulation of intangible assets can therefore distort the empirical results. As Van Beveren (2012) noted, TFP estimates are highly sensitive to the chosen methodology, and innovation indicators often capture only part of the underlying reality. To address this, we use indexed variable values and multicriteria composite indicators to capture the level of innovation as comprehensively as possible.

Our research focuses on assessing the effects of innovation, the quality of the business environment, the quality of the workforce, and the level of intangible assets on total factor productivity. By employing indexed data and composite indices, we aim to represent the level of innovation and its impact on productivity in a comprehensive manner. The role of intangible assets in overcoming productivity stagnation is evident. Thus, analysing the accumulation of such assets is crucial. Using panel regression with fixed effects and robust standard errors, we seek to contribute to the understanding of the role of innovation in total factor productivity across EU countries particularly within the Central and Eastern European (EU-CEE) region where previous evidence suggests a distinct pattern in the effects of intangible assets and innovation compared with other EU regions.

The paper is structured into three main sections. The first section introduces the topic and provides a basic overview of innovation, total factor productivity, and intangible assets. The second section reviews the current state of knowledge and relevant literature. The methodological section outlines the research principles and describes the empirical approach, followed by an analytical section presenting the results of the panel regression and the resulting policy implications. The final section concludes with a summary of the main findings, an evaluation of the results, and a discussion of the study's limitations.

## 1. Literature Review

The empirical discussion on total factor productivity (TFP) and the role of innovation has evolved over several decades. The neoclassical production function presented by Solow (1957), suggests that most TFP growth results from technological progress rather than from capital and labor accumulation. However, technological progress has become endogenous. Theoretical models of endogenous growth (Romer, 1990) emphasize the central role of knowledge as an internal determinant of growth. Innovation thus emerges as an inexhaustible and increasingly productive growth factor. Technological progress is therefore viewed as the outcome of economic decisions, particularly those involving investments in research and development. Within the Schumpeterian growth model, Aghion and Howitt (1992), drawing on Schumpeter (1942), introduced the concept of creative destruction, which explains that technological progress arises from innovations that replace obsolete technologies.

Innovation has therefore become the driving force of total factor productivity and long-term economic growth. However, innovation is neither uniform in nature nor in its effects. The discussion of innovation has shifted towards evolutionary economics (Nelson and Winter, 1982), where innovation is understood as a cumulative process of learning and adaptation productivity becomes an expression of firms' capacity to innovate through continuous learning. Innovations are typically classified into three main categories: (i) product innovations are most often associated with advancing the technological frontier; (ii) process innovations enhance the efficiency of resource use, although their effects may be limited without corresponding organizational changes; (iii) organizational innovations play a crucial role in ensuring that technological advances are effectively utilized (Masso and Vahter, 2012; Lee *et al.* 2019).

Intangible assets represent an essential component of innovation. Professor Veblen (1904, 1908) already anticipated their irreplaceable role in innovation and productivity, emphasizing that knowledge, skills, and habits of thought constitute key production factors. He also highlighted the importance of the institutional environment rules, norms, and organizations that either enable or hinder the effective use of knowledge and new technologies. Acemoglu, Johnson, and Robinson (2001) demonstrated that variations in institutional frameworks, such as the enforceability of law and the protection of property rights, have a fundamental influence on economic development. Similarly, Hall *et al.* (1999) showed that social infrastructure including institutional quality, the legal environment, and market mechanisms is a major determinant of productivity differences across countries. Balcerzak and Pietrzak (2015) reported in a sample of EU countries that institutional quality affects TFP dynamics, stronger institutions promote convergence and higher productivity. Investments in intangible assets, when not supported by appropriate institutional and regulatory frameworks (*e.g.*, intellectual property protection), may fail to realize their full potential. These insights were further developed by Corrado *et al.* (2009), who showed investment in intangible assets exceeded that in tangible assets. Corrado *et al.* (2025) and the OECD (2021) confirmed this trend in EU countries and demonstrated that investment in intangible assets has a significant positive effect on productivity growth. The assumption that differentiated innovation impacts TFP based on regional disparities is therefore validated. In Western Europe (EU-15), innovation is embedded within a long-term system of RandD support, strong institutions, and a high share of investment in intangible assets key drivers of productivity growth according to Roth and Thum (2013). In contrast, in Central and Eastern European (EU-CEE) countries, the mere presence of investment in intangible assets may be insufficient. For these economies, the maturity of cybersecurity plays an increasingly important role, as insufficient protection of digital assets can weaken the absorptive capacity of firms and reduce the effectiveness of intangible assets. Consequently, we assume that institutional quality is the key determinant of productivity and long-term growth, as it defines the "rules of the game." Countries with stable legal frameworks and effective intellectual property protection experience a stronger impact of innovation on TFP, whereas the opposite holds true for countries with weaker institutional quality (North, 1990).

Innovation is a crucial factor influencing TFP. This positive relationship has been demonstrated by Gu and Tang (2004) and Masso and Vahter (2012), who showed that innovative firms experience higher TFP growth rates than those that do not create or implement innovations. An important complement to innovation activities is the accumulation of intangible assets. There is growing evidence that investments in intangible ICT assets (software and databases), intellectual property, brands, patents, organizational knowledge, and employee training have a significant effect on productivity growth and value added. Corrado *et al.* (2009) established a methodological classification of intangible assets. Bloch *et al.* (2024) reported that intangible assets significantly contribute to productivity growth in developed economies. Pekarčík *et al.* (2022) demonstrated the positive impact of intangible asset on value added in global value chains. O'Mahony and Vecchi (2009) reported that the impact of intangible assets on productivity varies across sectors and highlighted the spillover effects of these assets. Roth and Thum

(2013) confirmed a robust positive relationship between investment in intangible assets and labor productivity growth at the EU country level via the INTAN-Invest database. Corrado *et al.* (2022) reported that the level of intangible assets in the EU lags behind that of the United States and showed that expanding the definition of assets to include newly recognized intangibles changes the understanding of TFP growth sources. Haskel and Westlake (2018) analysed the transition from a tangible economy to an intangible economy. The question of why information technologies (IT) investments do not always result in immediate productivity growth was examined by Brynjolfsson and Hitt (2003), who reported that the benefits of IT are linked to complementary intangible assets such as organizational structures and workforce skills. They also demonstrated the delayed positive impact of intangible asset accumulation on productivity. In the transforming economies of Central and Eastern Europe, ICT both tangible and intangible has played an important role in enabling rapid modernization and integration into global value chains (Pekarčík *et al.* 2022). The role of intangible ICT assets and cybersecurity was examined by Gordon *et al.* (2015), who demonstrated that regulatory requirements stimulate investment in security and process quality, effectively making security an element of organizational capital. Cybersecurity has become a core component of intangible assets, its effectiveness reinforces firms' ability to adopt advanced technologies, protect knowledge and maintain uninterrupted production process. Weak cybersecurity capabilities under intangible assets can therefore limit the production gains from ICT investment, especially in countries where digital infrastructure is expanding rapidly. The quality of human capital and its impact on TFP remain relatively debated. The mere presence of knowledge workers is not sufficient. The crucial factor is the ability to transform this knowledge into innovation and to integrate it within organizational structures. Roth and Thum (2013) showed that a more comprehensive statistical measurement of intangible asset dimensions strengthens the estimated impact on productivity. In general, the accumulation of intangible assets and the level of innovation significantly influence productivity and consequently, global competitiveness. Their support and development are therefore essential for enhancing productivity and competitiveness in modern economies (OECD, 2013). The literature thus reveals a shift from early exogenous and endogenous models toward more detailed quantitative and econometric analyses of the mechanisms and types of innovation, the role of intangible assets, and their impact on productivity.

The preceding chapters underscore the central role of intangible assets, innovation, and institutional quality as the primary drivers of long-term economic and productivity growth. They demonstrate that productivity dynamics increasingly depend on a country's capacity to accumulate, develop, and effectively utilize intangible assets such as knowledge capital, intangible ICT assets, organizational capabilities, and digital technologies. Our objective is to assess the extent to which the accumulation of intangible assets, the quality of the business environment, the level of human capital, and the diffusion of ICT assets contribute to total factor productivity growth.

## 2. Method

We apply a panel regression model with fixed effects to examine the impact of intangible asset accumulation, the quality of the business environment, the level of human capital, and ICT assets on total factor productivity (TFP). On the basis of the literature review, the research question is defined as follows:

How do innovation, the business environment, and intangible assets contribute to TFP growth?

The role of innovation and intangible assets in TFP growth has been extensively studied, yet further investigation is needed particularly regarding regional differences. Therefore, this paper employs two models: one covering all EU countries and another focused specifically on Central and Eastern European (EU-CEE) countries. Building on the theoretical foundations presented in the previous sections, we formulate three hypotheses:

H1: The accumulation of intangible assets has a positive effect on total factor productivity (TFP) growth in EU countries.

H2: Information and communication technologies (ICTs) contribute positively to TFP growth in EU-CEE countries.

H3: The quality of the business environment (BE) has a positive effect on TFP in EU-CEE countries.

Data for the total factor productivity variable are obtained from the Penn World Table database (Feenstra *et al.* 2025), which provides standardized national accounts data indexed to 2017=100. Data on intangible assets are sourced from the EU-KLEMS database (Bontandini *et al.* 2023), where we use the accumulation of total intangible assets (INTANG), which is also indexed. Data on the quality of the business environment and knowledge workers are derived from the Global Innovation Index (GII) compiled annually by the World Intellectual Property Organization (WIPO, 2025). Within the business environment category, the indexed data capture aspects such as regulatory quality, institutional efficiency, the legal framework, the tax burden, and access to finance. The knowledge workers variable reflects the quality of human capital, including research capacity, education and skills, and knowledge absorption. These composite indicators are suitable proxies for quantifying both the quality of the business

environment and human capital. All the data are standardized on a scale of 0–100. Indexed dataset allows the analysis to focus on relative dynamics rather than absolute levels, which is essential for the purpose of this article to capture structural relationships affecting TFP. We acknowledge that the main risk associated with indexation is the potential reduction of cross-sectional variance and the possibility of bias. To mitigate this, the models employ country fixed effects and robust standard errors, which limit the impact of heterogeneity loss and ensure consistent coefficient estimates. The dataset covers the period 2013–2019 and includes the following countries: Bulgaria, Croatia, the Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom. The total number of observations is 182, and the panel is balanced. The variance of the TFP variable is relatively low, whereas the other variables exhibit sufficient variability to allow meaningful estimation.

Table 1. Descriptive statistics

Tranche	N	Average	St. Dev	Min.	Max.
TFP	182	0.977	0.042	0.835	1.160
Business Environment (BE)	182	76.2	14.1	17.9	93.1
Knowledge workers (KW)	182	55.6	12.8	22.4	81.8
ICT	182	66.2	13.5	27.5	91.0
Intangibles	182	45.8	15.2	10.4	78.6

Source: Authors' calculations. Notes: Robust SEs clustered by country are in parentheses. \*\*\*, \*\*, \* denote  $p < 0.01$ ,  $p < 0.05$ , and  $p < 0.10$ , respectively. All the models include country FEs; year FEs are included in the robustness checks.

Table 1 presents the descriptive statistics for the variables used in the analysis. The TFP variable has an average value of 0.977 and a standard deviation of 0.042. The difference between the minimum (0.835) and maximum (1.160) values indicates a relatively narrow range. However, it still reflects notable differences among individual countries and time periods. The low degree of volatility corresponds to the fact that the data are indexed. The gap between the minimum and maximum values represents an approximately 40% difference in productivity, which is economically significant. The values for the business environment reveal marked heterogeneity among the countries studied. The lowest scores reflect a weaker institutional and regulatory framework, whereas higher scores represent more advanced and stable environments. A similar pattern is observed for the Knowledge Workers variable. Some countries exhibit a relatively low proportion of skilled labor, whereas others possess a highly developed knowledge base. The greater dispersion of this variable enables the identification of potentially strong effects of both the business environment and human capital quality. On average, values above 50 suggest that most countries qualify as knowledge economies, although several EU-CEE countries fall below this threshold. Importantly, a greater share of knowledge workers does not automatically guarantee higher productivity the key lies in transforming knowledge into innovation and process improvement.

The ICT variable shows that certain EU countries continue to lag in terms of digitalization and the adoption of modern ICTs across both the private and public sectors. In the literature, ICTs are recognized as general-purpose technologies with the potential to significantly influence TFP through process improvements. The degree of variability observed in ICT makes it possible to identify its effect on TFP, particularly in EU-CEE countries transforming economies in which ICT development is progressing rapidly and enabling modernization of products and processes. Finally, the intangible assets variable displays a relatively high degree of variability, which is expected given the differing national intensities of investment in this category.

### 3. Research Methodology

The main objective of this study is to analyse the dynamic relationships between innovation, the business environment, intangible assets and total factor productivity (TFP) across countries and over time. The Hausman test (Hausman, 1978) produced a value of 0.0000, confirming the appropriateness of the fixed effects model, which aligns with the assumption that country-specific factors influence productivity outcomes. Accordingly, we employ a fixed effects panel regression based on an extended production function that incorporates key determinants of productivity growth. This approach enables control for unobserved, time-invariant heterogeneity across countries through fixed effects, thereby mitigating potential estimation bias. At the same time, it captures structural differences

between national economies. Endogeneity may arise if institutional quality, ICT, or intangible assets jointly evolve with TFP. We address this risk by using a fixed-effects model and robust standard errors, which limits bias from time-invariant heterogeneity and serial correlation. A balanced panel dataset is used, and the time span is sufficient to identify the delayed effects of innovation, intangible assets, ICT, and institutional variables (BE and KW). On this basis, the main equation of Model (1) defines the econometric specification of the fixed effects panel regression:

$$TFP_{it} = \alpha_i + \beta_1 BE_{it} + \beta_2 KW_{it} + \beta_3 ICT_{it} + \beta_4 INTANG_{it} + u_{it} \quad (1)$$

where  $i$  indexes countries and  $t$  years (2013-2019);  $TFP_{it}$  = Total Factor Productivity; BE = Business Environment; KW = Knowledge Workers; ICT = Information and communication technologies; INTANG = Total Intangibles assets;  $u_{it}$  = Error; and  $\alpha_i$  = fixed effect (country).

A total of four models are estimated. The first model includes all EU countries with 182 observations and excludes lagged effects. The second model focuses solely on EU-CEE countries, with 156 observations and no lag structure. The third and fourth models introduce one-year lagged effects for the EU and EU-CEE samples, respectively. This design allows us to capture the dynamic nature of the relationship between inputs and productivity while reducing the risk of endogeneity. Lagged variables (Brynjolfsson *et al.* 2000; O'Mahony and Vecchi, 2009) are particularly appropriate for variables such as the business environment, knowledge workers, and the accumulation of ICT and intangible assets, whose effects often materialize with a delay.

Diagnostic testing confirmed the presence of heteroscedasticity and autocorrelation in the model residuals. Given the violation of homoscedasticity and independence assumptions, coefficients were estimated via the fixed effects method with robust standard errors clustered at the country level (Arellano, 1987), ensuring the consistency of the estimates. Multicollinearity was assessed via the variance inflation factor (VIF) test, which yielded a value of 1.77, indicating that there was no significant multicollinearity. The correlation matrix revealed a relatively greater correlation between BE and ICT, but this relationship remained within acceptable limits and did not distort the coefficient estimates.

#### 4. Research Results and Discussion

We conduct an econometric analysis of the impacts of intangible asset accumulation, business environment quality, the human capital level, and ICT infrastructure on total factor productivity (TFP) via a fixed-effects panel regression model. The Hausman test confirmed this specification by rejecting the consistency of random effects estimates. The analysis is performed for all EU countries and separately for the EU-CEE subgroup. We assume that TFP is determined by a combination of structural factors. The quality of the business environment, the level of knowledge workers, ICT infrastructure, and the accumulation of intangible assets. Furthermore, we assume that these effects may not occur instantaneously. Therefore, a panel regression model with a one-year lag is applied to capture delayed impacts.

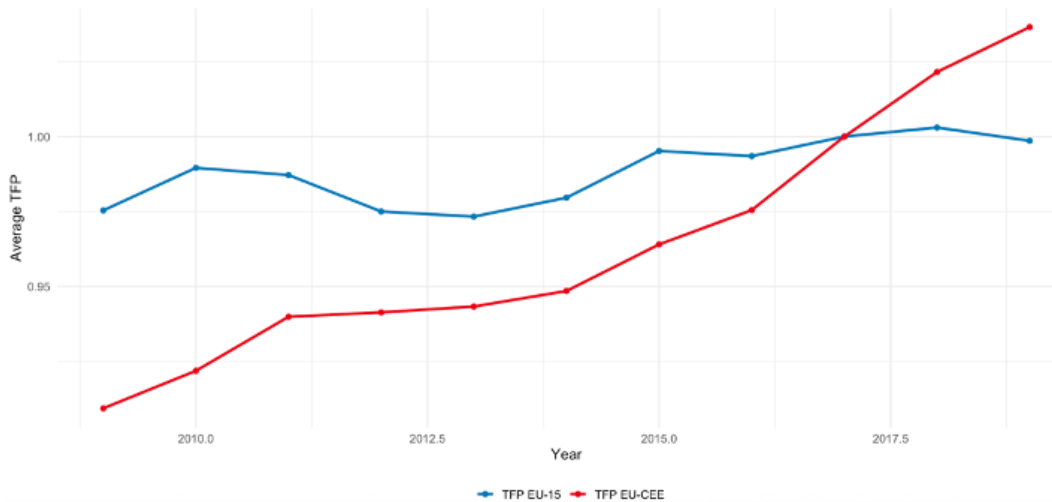
Figure 1 illustrates the development of total factor productivity (TFP) in Western European countries (EU-15) and the transition economies of Central and Eastern Europe (EU-CEE) between 2009 and 2019. All values are indexed to 2017 = 100. In 2010, the EU-CEE countries started from a significantly lower level of TFP, but their growth rate surpassed that of the EU-15 in 2016. The EU-15 countries have maintained a higher long-term TFP level, reflecting Western Europe's historical advantages in technological sophistication, human capital, and institutional quality. During the observed period, TFP in the EU-15 region remained relatively stable, whereas EU-CEE countries recorded steady gains since 2009. This trend suggests a catching-up effect, as transforming economies have managed to adopt new technologies more rapidly, improve their business environments, and leverage cost advantages in human capital. The pattern also indicates that TFP growth in EU-CEE countries is largely driven by the diffusion and adaptation of technologies developed elsewhere mainly in the EU-15 or globally.

For the EU-15 countries, the main challenge lies in the low dynamics of productivity growth, despite strong innovation potential. Conversely, for EU-CEE countries, the key challenge is to connect productivity growth more closely to their own innovation capacity to sustain convergence. Figure 1 thus illustrates both the convergence process of EU-CEE countries and the structural barriers that differentiate their productivity trajectories from those of Western Europe.

The most important and robust finding is the consistent statistical significance of the variable representing the growth of intangible assets (Intangibles). In both unlagged models for EU and EU-CEE countries, the coefficient equals 0.005 with a robust standard error of 0.001 at the 1% significance level, clearly confirming the strong positive relationship between investment in intangible assets and TFP. The coefficient for intangible assets (0.005) indicates that a ten-point increase in intangible asset accumulation corresponds to an estimated 5% increase in TFP. These results support the first hypothesis, namely, that the accumulation of intangible assets positively affects total factor

productivity growth in EU countries. A similar positive result is observed when one-year lagged effects are incorporated.

Figure 1. Development of TFP in the EU and EU-CEE, 2017=100



Source: Authors' calculations

These findings are consistent with the well-established view that intangible assets play a crucial role in contemporary economies, particularly in driving productivity and supporting the transition toward a knowledge-based economy (Corrado, Hulten, and Sichel, 2009; Haskel and Westlake, 2018). Our results confirm these arguments and further show that, even within the EU-CEE region, the productivity growth model is founded on the accumulation of intangible assets. The model with lagged effects indicates that this influence is persistent over time, which is consistent with the conclusions of Roth and Thum (2013). The role of the regulatory and institutional environment proves to be particularly significant in transition economies. Our findings suggest that regulatory and institutional reforms do not immediately affect productivity but rather exhibit a delayed effect once new rules and frameworks have been stabilized and begin influencing the business environment. This result aligns with the argument of Acemoglu, Johnson, and Robinson (2001), who demonstrated that institutional quality is a fundamental determinant of economic performance. The same conclusion applies to the business environment more broadly, which constitutes a key determinant of a country's capacity to absorb and apply foreign technologies (Griffith, Redding, and Van Reenen, 2004; Stettler *et al.* 2024). The business environment coefficient differs between the EU and EU-CEE models. For the EU-CEE sample, the coefficient of 0.002 is statistically significant at the 5% level. A positive and stronger impact is also evident in the lagged models, where the coefficient remains significant at the 1% level. Specifically, a one-point increase in the GII business environment index is associated with a 0.2% increase in TFP, whereas a ten-point improvement corresponds to an average 2-3% increase in TFP in EU-CEE countries comparable in magnitude to the impact of intangible asset accumulation. These magnitudes underscore the economic significance of business environment and intangible investment, confirming that both variables exert substantial and policy-relevant effects on productivity. These results confirm the third hypothesis. Furthermore, the persistence of these effects indicates that improvements in institutional quality contribute to sustained productivity growth and enhance convergence within the EU-CEE region through multiplier effects.

Our results also reveal that, for EU-CEE countries, the ICT variable (0.001) has a statistically significant lagged effect at the 5% level. The findings also suggest that in digitally converging EU-CEE economies, the productivity effect of ICT may depend not only on diffusion and absorptive capacity but increasingly on the quality of cybersecurity practices, which protect digital intangible assets. However, historically EU-CEE economies have operated at lower levels of technological development, where ICT adoption yields high marginal benefits. Consequently, ICT expansion contributes to greater efficiency and modernization of production and business processes. In contrast, EU-15 countries having implemented ICT infrastructure much earlier experience productivity gains from ICT only when complemented by additional investments in organizational innovation and human capital (Brynjolfsson and Hitt, 2003).

van Ark, O'Mahony, and Timmer (2008) reported that U.S. firms were able to leverage complementary intangible assets more effectively to increase productivity. Our results are consistent with this evidence, in

economies where ICT is still developing, its contribution to productivity is especially pronounced. The heterogeneous regional effects are further supported by Rehman and Nunziante (2023), who showed that the expansion of the digital economy contributes positively to TFP at the regional level, although this contribution varies across regions. Collectively, these findings confirm the second hypothesis.

Table 1. Panel regression fixed effect results

	Depend variable: TFP			
	EU no lag	EU-CEE no lag	EU lag	EU-CEE Lag
	1.	2.	3.	4.
Intangibles	0.005*** (0.001)	0.005*** (0.001)	0.004*** (0.001)	0.004*** (0.001)
Business Environment	0.001 (0.001)	0.002** (0.001)	0.003*** (0.001)	0.002*** (0.001)
Knowledge workers	0.003 (0.003)	0.000 (0.000)	0.001 (0.000)	-0.001 (0.000)
ICT	0.001 (0.004)	0.001** (0.000)	0.0003 (0.000)	0.001** (0.001)
No.	182	77	156	66
Adjusted R2	0.520	0.748	0.425	0.716
F stat.	56.287***	60.001***	35.941***	44.507***

Source: Authors' calculations Notes: Robust SEs clustered by country in parentheses. \*\*\*, \*\*, \* denote  $p < 0.01$ ,  $p < 0.05$ , and  $p < 0.10$ , respectively. All the models include country FEs; year FEs are included in the robustness checks.

The Knowledge Workers variable does not show statistical significance in any of the models. The GII indicator captures the supply of skilled labor but not the conditions that determine whether this human capital is effectively used within firms. Our results also suggest qualified workers contribute to TFP only when they have been supported by complementary intangible assets, organisational practices, and a stable institutional environment. In their absence in EU-CEE region the impact of knowledge workers on productivity remains limited. Although a positive relationship is observed, it is not statistically significant. The assumption that a high level of knowledge workers automatically enhances TFP growth is therefore not supported. However, the results confirm that the mere presence of highly qualified human capital is insufficient if it is not complemented by concurrent investments in intangible assets such as training, education, and economic competencies as well as organizational innovations. At the firm level, Syverson (2011) similarly reported that differences in productivity among firms often do not reflect the number of skilled workers but rather the quality of management, which determines how effectively these workers are utilized. The model itself explains a substantial share of TFP variability. The F statistics across the models confirm that the estimated regression relationships are statistically significant. The panel regression results provide important insights into the differentiated sources of TFP growth in EU countries, particularly between Western and Central and Eastern European (EU-CEE) regions. Our findings confirm that the determinants of TFP growth vary by development level. In EU-CEE countries, alongside the accumulation of intangible assets, both the quality of the business environment and ICT infrastructure play critical roles. Promoting the accumulation of intangible assets should therefore be a key policy priority. This includes fostering investment in research and development, software and databases, intellectual property, and organizational capital. Our analysis further confirms that a high-quality business environment is essential for supporting TFP growth. Consequently, EU-CEE countries should prioritize improving institutional frameworks and regulatory quality. Without such reforms, sustaining higher rates of productivity growth will be difficult.

Efforts to enhance human capital quality should focus not only on expanding education but also on improving conditions for the effective employment of knowledge workers particularly through the creation of innovation ecosystems. The results also confirm that the effects of intangible asset accumulation and business environment

quality are delayed, implying that economic policy should be designed from a long-term perspective. Overall, the different results across EU regions highlight the need for distinct economic policy strategies. Stable and predictable decision making in these areas is essential. In progressive digitalisation of production in EU-CEE the strengthening of cybersecurity frameworks could become an increasingly important complementary factor that protect digital intangible assets and support durability of ICT driven productivity growth. For EU-CEE countries, institutional reforms, investment in ICT infrastructure, and the accumulation of intangible assets remain key to accelerating convergence and sustaining greater TFP growth.

### Conclusions and Further Research

The aim of this study was to analyse the determinants of total factor productivity (TFP) in EU countries, with particular attention given to the transition economies of Central and Eastern Europe (EU-CEE). Using panel regression with fixed effects and robust standard errors, we examined the relationships between TFP and four key factors: the quality of the business environment (BE), the development of information and communication technologies (ICTs), the quality of knowledge workers (KW), and the accumulation of intangible assets (Intangibles). By employing indexed variables as proxies, the analysis captured the multidimensional nature of institutional and business environment quality as well as human capital. The fixed effects specification ensures the econometric validity and robustness of the estimated results.

The most consistent and robust finding is the strong significance of the variable representing the growth of intangible assets. The results confirm that both the quality of the business environment and the accumulation of intangible assets are key determinants of total factor productivity growth. Productivity in the EU is therefore largely driven by investment in intangible assets, which exert a stable and statistically significant effect across all the models. This finding highlights the irreplaceable role of intangible investments as a principal source of productivity growth, which is consistent with Corrado, Hulten, and Sichel (2009). A similarly significant effect was observed for the business environment variable, particularly within the EU-CEE group, underscoring the differentiated determinants of TFP across regions. Institutional reforms and improvements in the quality of the business environment are thus crucial to sustaining productivity growth in these countries.

This study is subject to several limitations. The availability and timeliness of macroeconomic data particularly the conceptual consistency of national account data and supplementary EU-KLEMS information may influence the results. Potential biases may also arise from the use of indexed variables, which can obscure national-level heterogeneity. The fixed effects model captures structural relationships but does not allow for dynamic interactions among variables. Methodological extensions such as panel VAR or other dynamic panel models could uncover effects between intangible assets, ICT, institutional quality, and productivity. Future research should therefore focus on the detailed application of microeconomic data, such as firm-level datasets, to better capture the mechanisms of intangible asset accumulation and its effects. Given the short time span of the dataset, more advanced estimators such as Hausman-Taylor, or GMM could not be applied reliably, but they represent suitable extensions for future research once longer and harmonised new data become available. Moreover, future analyses could incorporate interaction variables, which according to the literature play a critical role in generating synergy effects among innovation-related factors.

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**Marek Pekarčík:** Conceptualization, Investigation, Methodology, Software, Formal analysis, Writing – original draft, Data curation, Validation.

**Leoš Šafár:** Conceptualization, Methodology, Project administration, Supervision, Writing – review and editing, Funding acquisition.

**Tatiana Taňkošová:** Formal analysis, Data curation, Supervision, Writing – review and editing, Visualization.

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