Revisiting the Productivity Paradox: What is Next for the BRICS and European Banking Systems?

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ABSTRACT

Information technology is a critical driver of productivity growth in modern economies. However, there has been no convincing explanation for the observed discrepancy in the literature, increasing suspicion on whether IT can improve institutional performance in contemporary banking markets. The fallacy of productivity adds credence to Robert Solow's dictum, "You can see the computer age everywhere except in productivity statistics". We employ two extensive bank-level datasets of 5,794 institutions across 37 nations to estimate the total factor productivity (TFP) payoffs from IT in BRICS and European markets. A DEA-based, Malmquist productivity index quantifies TFP change and its respective components. Findings provide evidence against the paradox as both regions experience IT-fueled productivity growth. Nevertheless, such associations vary across banking sector development, rationalizing how IT spending can explain productivity differences across nations. For BRICS banks, a significant proportion of TFP growth originates from frontier expansion instead of frontier progression, signaling a widening of technology gap. Contrastingly, IT has diminished the technology gap between European banks. Intra-country comparisons suggest that if IT-driven productivity growth is regarded as a nation's long-term goal, industry characteristics should govern the distribution of knowledge capital.

KEYWORDS

Total Factor Productivity, Data Envelopment Analysis, Commercial Banks, BRICS, Europe

INTRODUCTION

Information technology (IT) has become a critical driver of productivity growth in modern economies. The use of IT in business operations has resulted in increased efficiency, reduced costs, and improved productivity, making it an essential component of many successful organizations (Allen et al., 2008; Doluca & Doluca, 2012; Juhro et al., 2020). IT-led productivity growth is viable due to the capacity of technology to streamline processes, automate tasks, and improve communication, leading to increased competitiveness and economic growth (Islam & Fatema, 2020). Additionally, technologically-driven strategies positively influence the marginal product of labour and, as such, can enhance workplace productivity (Obeng & Boachie, 2018). Digital disruption continues to alter the financial environment and pressure the conventional banking model; in the meantime, banks are finding it increasingly challenging to develop as the global economy has stagnated post-COVID-19 pandemic. To succeed in this climate, banks must develop highly effective IT delivery solutions (Kanagasabai et al., 2019). As a consequence, banks striving to improve performance and achieve sustainable development in the current market environment must comprehend the significance of IT-driven productivity growth (Jevtić et al., 2014). However, there has been no convincing explanation

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for the observed disparity in the literature on the productivity benefits of IT, leading to skepticism as to whether IT can improve company performance in modern banking markets. The apparent fallacy of productivity adds validity to Robert Solow's dictum, "You can see the computer age everywhere except in productivity statistics" (Solow, 1987). The so-called productivity conundrum in the banking business alludes to the notion that the industry has not seen significant productivity improvements despite considerable investments in information technology.

While digitization is pervasive in all industries, the banking sector has embraced novel banking solutions, with banks investing heavily in IT infrastructure, software, and other related technologies to increase productivity and efficiency (Kwateng et al., 2019; Singh, 2023). The emergence of data analytics and artificial intelligence (AI) has enabled banks to improve corporate decisions and provide personalized services to clients. The use of AI has resulted in hyper-automation, which streamlines repetitive operations along with processing and analyzing massive amounts of data, that can be used to provide personalized banking experiences to customers (Singh, 2023). The introduction of cloud-based functionality on the core banking systems has further altered overhead IT costs and has resulted in improved speed and quality of customer service (Kanagasabai et al., 2019). However, despite such investments, there has been little evidence of corresponding productivity gains (see, inter alia, Shu & Strassmann, 2005; Chen & Xie, 2015; Siek & Sutanto, 2019; Elkmash, 2022). One possible explanation for the productivity paradox in the banking sector relates to inadequate implementation, lack of training, and resistance to change (Buchak et al., 2018; Hornuf et al., 2021). In addition, regulatory requirements, market volatility, and the complexity of the industry constrain productivity gains in the banking sector (Kasman & Carvallo, 2014; Nguyen & Nghiem, 2017; Rakshit & Bardhan, 2020; Prakash et al., 2021a).

Carr (2003) relates the productivity fallacy to the commoditization of IT, in which incremental advances and a lack of protection weaken its strategic value. Brynjolffson and Hitt (1995) dispute the measurement aspect of the phenomena, arguing that IT investments, as a combination of product and process innovations, have a wide-ranging effect on the whole organization, labelling the study of productivity payoffs as a myopic perspective of IT. Another body of research (Harris, 2001; Cullmann et al., 2009; Jevtić et al., 2014: Kijek & Kijek, 2018) focuses on innovation as a mediator in resolving the productivity conundrum and emphasizes the significance of research and development (R&D) expenditures in generating positive returns from IT investments. Brynjolfsson and Saunders (2009) argue that IT capital offers a competitive advantage to the extent that it is sustained by R&D spending. Obeng and Boachie (2018) advocate that superior returns from IT are not attainable unless the strategies are aligned with the end user and successfully meet their needs. On the other hand, proponents of a new economy relate the paradox to an occurrence of the 20th century, disputing its presence in the current arrangement (Prasad & Harker, 1997; Casolaro & Gobbi, 2007; Doluca & Doluca, 2012; Romdhane, 2013; Arabyat, 2014; Prakash et al., 2021b).

In light of the above background, the present study attempts to gauge the productivity payoffs of information technology in the BRICS and European banking markets. The selection of regions was primarily motivated by a desire to comprehend the differential effects of IT investments in emerging market economies and developed market economies. On the one hand, the BRICS nations encompass swiftly emerging economies that seem to operate on the size and trajectory of advanced nations and continuously expand their influence in global economic affairs. Moreover, among the BRICS countries, the financial sector is one of the most rapidly developing industries (Wang et al., 2021). The technological advancements in the financial arena of BRICS nations have altered the present competitive environment and unleashed the enormous potential for technology-driven productivity growth (Umar et al., 2018). Technological adoption has also resulted in the emergence of new business models. The partnership between traditional banks and fintech companies has created new business avenues, making banking accessible, affordable, and efficient (Singh, 2023). However, similar to other emerging countries, the banking industry of BRICS is plagued by various technical, regulatory, and structural obstacles that impede its potential (Sharma & Anand, 2018; Guru & Yadav, 2019; Moudud-Ul-Huq, 2020). Consequently, the intricacies of the BRICS countries are symbolic of emerging market economies.

The European bloc, on the other hand, consists of nations with homogenous traits that were established specifically for the purpose of creating a monetary union. The European banking markets are developed and resilient to liquidity and economic shocks (Pradhan et al., 2020). The issue of technological upgradation, while not new, has been one of the primary objectives of European commercial banks (Fusco & Maggi, 2021). Historically, European commercial banks have been able to justify IT investments with commensurate productivity gains (Kanagasabai et al., 2019). Nonetheless, the drive for modern digital transformation has presented European commercial banking sectors with two obstacles. First, the rise of new market entrants in the shape of fintech startups and large technology companies has transformed the industry's present competitive environment (McNulty et al., 2022). Most of these businesses can provide superior services to the populace efficiently and are generally unaffected by the regulatory restrictions encountered by conventional banks. This has resulted in conventional banks outsourcing their digital needs to third-party service providers. Such dependency, however, presents a new operational risk in the form of cybersecurity issues (Pradhan et al., 2020). The expectation is that European banks would adequately manage this risk and have contingency measures in place to deal with service disruptions (McNulty et al., 2022). Nevertheless, European banks have been the leaders in embracing technological change (Kumbhakar et al., 2012). Consequently, the peculiarities of the European banking sector correspond precisely with the classification of advanced market economies.

The study extends the available literature on the following lines. First, we quantify total factor productivity (TFP) change through a non-parametric, data envelopment analysis (DEA) based dynamic sequential Malmquist-Luenberger productivity index (DSMLPI). The traditional specifications used for quantifying TFP growth, such as those given by Caves et al. (1982) and Chung et al. (1997), have a disadvantage in terms of the fact that they are entirely based on a black-box representation of the production technology. Similar to the approach advocated by Bansal et al. (2022), we define the internal functioning of a typical commercial bank by specifying a dynamic, three-staged production process, consisting of an array of mutually exclusive processes that can be linked to distinct production activities via carryovers and intermediate products. The proposed DSMLPI links different divisions via intermediate products and different periods via carryovers, and as such, provides a holistic overview of the production structure. The index further tackles the classic infeasibility problem emanating from the incorporation of negative data values, considers undesirable inputs and outputs, provides for the inclusion of quasi-fixed inputs, and facilitates a sequential enveloping of preceding technologies in constructing the benchmark for successive periods (Bansal et al., 2022). The DSMLPI is subsequently bifurcated change into technical efficiency change (EFFCH) and technical progress (TECHCH), which are of critical importance to gauge the differential impact of IT in enhancing (impeding) productivity growth. Indeed, based on the position of a country on the constructed frontier, IT can have a differential influence on productivity. This is of prime importance when conducting a comparative study of the banking sectors of the two geopolitical regions that differ in development. Second, we employ two comprehensive bank-level datasets comprising 5,794 institutions across 37 nations from 2005 to 2023, culminating into 84,493 bank-year records, permitting meaningful interpretations and generalizations. Third, the findings provide insight into how IT has narrowed (widened) the productivity gap among individual commercial banks across nations. Fourth, the findings highlight the importance of R&D spending in extracting the benefits of IT-fueled productivity growth. The results demonstrate that the central banks of the BRICS countries should aggressively encourage banks to leverage R&D to broaden the production frontier. In contrast, to decrease waste and promote efficiency, the European Central Bank should prioritize IT investments in European banks with low R&D expenditure.

The paper is structured as follows. Section 2 critically examines the existing literature on productivity payoffs from IT in banking markets. Section 3 highlights the data sources, research methodology, and key variables employed in the study. Section 4 describes the key findings of the study. Section 5 concludes the study with some recommendations for the bank managers and central banks of the two geopolitical blocs. Section 6 elucidates the limitations of the present study and possible future research directions.

LITERATURE REVIEW

THE PRODUCTIVITY PARADOX OF INFORMATION TECHNOLOGY

In the past three decades, the thrust toward IT has transformed how banks conduct operations. The effect of IT expenditures on bank performance is crucial since these investments represent a significant portion of expenses and have a major impact on bank strategies and processes. Further, IT investments impose stringent restrictions on the kind of goods and distribution channels provided, the achievable customization level, and the speed with which banks can react to market opportunities and threats (Abubakar & Tasmin, 2012; Maggio & Yao, 2020). The motivation for IT investments in the banking business stems from the inherent nature of banking operations, which is to strategically collect, handle, and utilize information (Casolaro & Gobbi, 2007). This suggests a strong relevance of IT spending, which has manifested in several dimensions over time. First, technology has permitted the creation of new, more complex products as well as the formation of new distribution routes to complement the conventional dimensions of the branch network (Collan & Tetard, 2007). Second, IT influences how banks conduct their activities, with the deployment of new and innovative technologies anticipated to decrease bank expenses over time (Beccalli, 2007; UNCTAD, 2017). Third, IT investments are viewed as a "necessity" to pursue cost minimization and revenue maximization, both of which are important strategic goals of BRICS and European banks. Fourth, banks perceive IT investments as an "opportunity" to accomplish an increasingly recognized strategic objective: quality improvement (Wu, 2022). Last, technological advancement has been generally acknowledged as one of the most significant drivers of change in the banking business. Nevertheless, the productivity paradox observed by Solow provides contrasting explanations regarding the strategic returns from IT investments.

Further, the expanding research in the IT field stems from the fact that IT plays a critical role in shaping the long-term success of the organization (Bakos & Kemerer, 1992). Besides being a source of competitive advantage, IT investments act as a multifaceted value-generating activity that reduces costs, increases profits, and improves efficiency (Wu, 2022). Investment in IT, just as in the case of any capital budgeting decision, requires excellent skill and knowledge, as these decisions have long-term consequences on the survival, growth, and future direction of a business (Chowdhury, 2003; Chava et al., 2013). Improper implementation of IT projects may lead to business failure (Arabyat, 2014). Further, the resource-based view (RBV) posits that firms in an industry compete based on heterogeneous resources that are rare, valuable, difficult to imitate, and non-substitutable (Barney, 1991; Hanif et al., 2022). In the context of IT, this view implies that resources like technical expertise, IT patents, innovations, and a technologically literate labour force give rise to possible sources of competitive advantage in the industry, as opposed to investment in basic hardware and equipment (Binuyo and Adewale, 2014). In the same vein, the success of any IT innovation depends upon its efficient implementation by an individual bank (supply-side economies) as well as the intensity of its adoption by the consumers (demand-side economies) (Abubakar & Tasmin, 2012). Maggio and Yao (2020) provide two perspectives linking technological innovations to industry development. The supply-side perspective contends that technological innovations result from intense competition among market participants. For example, many commercial banks have introduced mobile banking applications using application program interface (API) to counter the rise of third-party settlement operators and payment banks. On the other hand, the demand side perspective asserts that technological innovation results from ever-changing customer needs and requirements, which ultimately necessitates banks to adopt revolutionary technologies. These push and pull perspectives, along with the life cycle of the industry, pave the way for technological adoption and lead to sector development. Bakos and Kemerer (1992) contend that IT investments can provide the organization with economies of scale (low per-unit cost with each additional customer), economies of scope (using the same networking systems to offer allied services), and network externalities (benefit of having the majority of customers on a singular system).

While the advantages of IT expenditures in the banking industry have been extensively extolled, there is a dearth of empirical data to support the claim that IT has led to substantial productivity increases in banking markets. A literature analysis on IT productivity in the banking industry indicates a complicated and diverse problem. Brynjolfsson and Hitt (1995) demonstrate that IT investments are related to greater levels of productivity in the banking industry when accompanied by organizational reforms and investments in complementary assets such as staff training. In contrast, Liao and Wong (2008) indicate that IT expenditures have no meaningful influence on banking sector productivity owing to variables such as poor staff engagement and insufficient IT infrastructure. Similarly, Chen and Xie (2015) contend that IT investments correlate with greater productivity levels, but only in institutions with a culture of innovation and experimentation.

Understanding and resolving the IT-productivity conundrum in the banking industry demands a comprehensive and multidisciplinary approach. This is because the link between IT investments and productivity is contingent on various organizational, cultural, and technical variables. Organizational variables, such as the degree of centralization or decentralization in a bank's decision-making process, may substantially impact the productivity benefits realized from IT expenditures. According to McNulty et al. (2022), IT investments are more likely to increase productivity in banks with decentralized decision-making procedures since this allows for greater flexibility in adapting to changes in customer needs. Cultural variables, such as the amount of staff involvement and the innovation culture inside a bank, may also substantially affect productivity improvements.

Additionally, technological considerations, such as the quality of IT infrastructure and the level of integration between various IT systems, may substantially influence the goal of achieving IT-fueled productivity growth. Liao and Wong (2008) indicate that IT expenditures have no meaningful impact on productivity in the banking industry owing to inadequate IT infrastructure. Further, Islam and Fatema (2020) contend that investments in customer relationship management (CRM) systems are associated with significant productivity gains in the banking industry, owing to the capability of these systems to provide real-time information and insights into customer preferences and needs. Li et al. (2017) observes that investments in big data analytics are related to considerable productivity benefits due to the capacity of these systems to analyze massive quantities of data and give insights into customer behavior and market trends. Further, investments in complementary assets, such as personnel training and organizational improvements, can hold the key to maximizing the productivity gains from IT investments (Aiello & Cardamone, 2012).

A significant limitation of the existing literature on IT-performance associations is the assumption that all decision-making units utilize the IT budget efficiently (Weill & Olson, 1989). The authors introduce the concept of conversion effectiveness, which defines the degree to which a firm can effectively leverage IT investments to enhance productivity. In other words, the efficacy of IT investments in enhancing firm value primarily depends on how efficiently a firm utilizes the IT budget.

Possible efficiency sources include strategic alignment of IT policy with the overall policy, a trained and motivated workforce, and better management practices (Ugwuanyi & Obinne, 2013; Bloom et al., 2014; Qiu et al., 2018; Wu, 2022).

In the same vein, Asongu et al. (2017) contend that the gap between financial services and information technology services has narrowed, and hence, banks must concentrate on developing proprietary IT products to stay relevant in the market. Thakor (1999) states that banks must focus on developing in-house IT innovations that can be used as a competitive advantage instead of outsourcing them to IT-oriented firms. However, in the long run, banks must focus on finance-IT consolidation in the form of shared information systems, cross-networking, and standardization to reduce costs, ensure customer satisfaction, and bring uniformity across the banking system of a country (Bloom et al., 2014; Hornuf et al., 2021; Shanmugam & Chandran, 2022; He et al., 2022).

Reviewing empirical studies, Kumar (2013) employs a two-step method to assess the changes in the TFP of Indian commercial banks using the DEA-based Malmquist index and associates these changes to IT innovations in the banking industry utilizing a conventional regression framework. The results indicate that the Indian banking sector has experienced TFP gains at a rate of 11 percent. The author attributes this expansion to a 28 percent increase in technological development (frontier shifts), substantially correlated with the growth in RTGS and NEFT volumes. In a similar vein, Sufian (2011) calculates the output-oriented DEA-based Malmquist index of Chinese commercial banks and relates the changes in productivity levels to different bank-specific characteristics (size, market share, and risk). The Chinese banking industry has seen a 13 percent increase in productivity. However, banks with large market shares, higher credit risk, and higher operational costs have depicted decreasing productivity levels, while China's accession to the world trade organization (WTO) has positively influenced the technical efficiency of commercial banks.

Focusing on the Albanian commercial banking sector, Kalluci (2018) decomposes the TFP change into scale efficiency, pure technical efficiency, and technical progress by employing the Malmquist index. The results conclude that Albanian banks depict a positive trend concerning technical efficiency change. However, this change has been countered by a substantial decrease in technical progress (regress), which has resulted in stagnant TFP levels. Further, Rezitis (2006) employs the Malmquist index to calculate changes in TFP in the Greek banking industry by using a panel dataset and employs Tobit regression to determine the drivers of productivity change. The results reveal that market concentration and IT investments are the two main drivers of TFP growth.

Bansal et al. (2022) employ a modified version of the Malmquist-Luenberger productivity index on a sample of Indian banks by defining a sequenced production environment under the variable returns to scale (VRS) assumption to conclude that productivity change is driven by technical progress. Zhu et al. (2023) utilize an allocative MPI under the assumption of cost minimization and determine that input prices determine productivity change in the Chinese banking industry. On similar lines, Gökgöz et al. (2023) employ a two-stage DEA-based Malmquist productivity index to highlight the possibility of technical improvements for Turkish banks. Veluthedan and Kiran (2023) advocate that the growth of digital financial services is a critical driver for productivity growth in the Indian banking industry.

In contrast, Chen and Xie (2015) conclude that IT investments negatively impact average productivity levels, giving rise to the paradox of productivity in the Chinese banking sector. However, the authors relate these findings to the fact that the long-term benefits of IT diffusion across the banking sector will eventually overpower the short-term drag on productivity levels. In a landmark study, Ram Mohan and Ray (2004) employ Tornqvist and Malmquist TFP indices to measure the differences between productivity changes in Indian public and private sector banks. They attribute higher productivity levels of public sector banks to a shift in their orientation from social welfare to profits and the role of scale economies and IT investments in achieving these profits. Further, Mittal and Dhingra (2007) examine the role of IT investments in influencing the efficiency scores of Indian commercial banks and conclude that new private sector banks are the most innovative commercial banks as they reflect an increasing trend in productivity levels.

In contrast, many empirical studies have dismissed the notion of Solow's paradox altogether (Haynes & Thompson, 2000; Casolaro & Gobbi, 2007; Arora & Arora, 2013; Prakash et al., 2021a). The discrepancies in academic literature regarding the IT investment-performance link can be attributed to measurement problems, differences in sample size, nature of data, selection of performance measures, choice of methodology, as well as country-specific factors such as the degree of regulation, economic environment, and the extent of technological development (Thakurta & Guha Deb, 2018). Shin (2001) contends that the relationship between IT investments and performance is not direct and is conditional upon the organization's strategic choices. The results further conclude that firm-specific business strategies moderate the relationship between IT and business performance. The success of IT investments depends upon the degree of conjunction (coordination) between IT strategy and the overall business strategies. On similar lines, Lin (2007) attributes the ambiguity in the IT investment-performance link to measurement problems by advocating that IT investments lead to the development of IT capabilities (the ability of a firm to deploy IT investments in congruence with other resources), further enhancing performance. Hence, the effectiveness of IT investments is mainly dependent upon the ability of a firm to create IT capabilities.

TFP AND THE DYNAMIC SEQUENTIAL MALMQUIST-LUENBERGER PRODUCTIVITY INDEX (DSMLPI)

For a multiple-output multiple-input business firm, the term productivity is defined as the ratio of aggregate outputs to aggregate inputs at a given state of technology (Kumar, 2013). Further, productivity is also defined in terms of technical changes and innovations that lead to product (or process) improvements. These incremental improvements enhance the ability of a firm to produce more output with the given quantity of inputs or use fewer inputs to produce a given quantity of output – a concept famously recognized by Fare et al. (1994) as technical efficiency change. Further, technological improvements shift the benchmark production frontier outwards over time (Romer, 1990). These shifts are characterized by technical progress.

Keskin and Degirmen (2013) advocate that partial productivity measures, which define the change in output due to a unit change in a single input (say labour or capital), may lead to erroneous conclusions, as they do not reflect the changes in overall productivity levels. Hence, any productivity measurement technique must include all factors of production in its analysis. TFP, defined as the degree of intensity of multiple inputs used to produce multiple outputs, is one such measure (Comin, 2006).

Solow (1956) defines TFP as the proportion of output quantities not explained by the traditional inputs being used in production. Measured in terms of Solow's residual, TFP growth can be quantified, subject to the fulfillment of three assumptions: a neoclassical production model, perfectly competitive factor markets, and accurate measurement of input growth rates. Solow contends that in a perfectly competitive factor market exhibiting constant returns to scale, the entire quantity of output gets exhausted in meeting the marginal costs of traditional factor inputs: labour and capital. Hence, in a neoclassical growth model, a firm is not in a position to pay (and recoup) any costs relating to innovation. Subsequently, Romer (1990) attempts to relax the strict assumptions of the neoclassical model by allowing firms to earn supernormal profits from patented innovations. Aghion and Howitt (1992) extend this argument by stating that innovations in IT and R&D grant monopolistic rights to the innovating firm, allowing it to charge a higher marginal revenue relative to marginal costs.

Change in TFP represents the performance of an industry over time. Changes in productivity levels can occur either due to a complete shift of the production surface (frontier shifts) or due to an individual firm moving towards or away from the production surface (technical efficiency change) across time (Rezitis, 2006). The Malmquist index is one such measure that calculates these changes (Malmquist, 1953). In simple terms, the Malmquist index measures the ratios of output and input quantities in the case of a single input-output firm (or the ratio of technical efficiencies in the case of a multiple input-output firm) at a reference level of technology (Shafer & Byrd, 2000; Ram Mohan & Ray, 2004).

Further, a large body of work on DEA (Parsons et al., 1993; Das et al., 2005; Fiorentino et al., 2006; Prakash et al., 2022) pertains to its application in static models. However, there is a need to understand that specific factor inputs (for instance, IT investments) are undertaken in the current period to provide benefits at a future point in time (Scott et al., 2017). The DEA-based Malmquist index approach is one such methodology that studies the dynamic changes in TFP in time-dependent situations (Tone, 2004). The index facilitates the decomposition of the changes in TFP into catch-up effects (technical efficiency change) and frontier effects (shifts in the frontier). The catch-up effects, also known as recovery, refer to the improvements or deterioration in the efficiency level of a decision-making unit (DMU) over time. On the other hand, frontier effects (innovations) refer to a shift in the benchmark production frontier between two periods that may happen because of innovations, better technology, efficient processes, or other industrial factors (Tone, 2004).

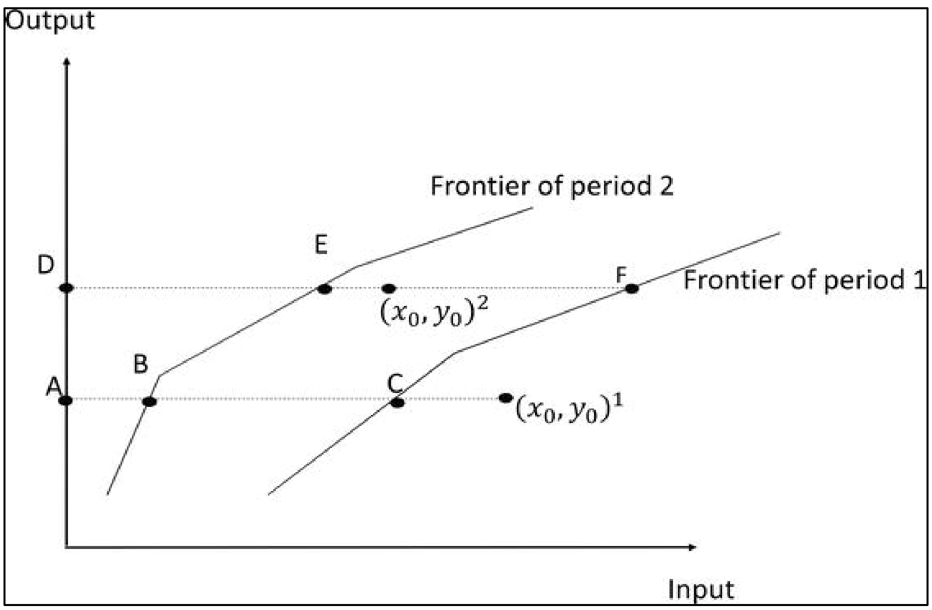

Figure 1. Decomposition of the Malmquist Index for a Single Input, Single Output Firm

The concept of the Malmquist index can be described by a single input-single output model (Tone, 2004). As illustrated in Figure 1, $(x_0, y_0)^1$ and $(x_0, y_0)^2$ represent the input and output vectors of the same DMU in periods one and two, respectively. Let P and Q denote the production levels using the vectors $(x_0, y_0)^1$ and $(x_0, y_0)^{2,}$ respectively. Consequently, the technical efficiency change of the DMU across two periods can be represented as follows:

$$Catch - up = \frac{Efficiency\ of (\mathrm{x_0,y_0})^2\ w.r.t\ period\ two\ frontier}{Efficiency\ of (\mathrm{x_0,y_0})^1\ w.r.t\ period\ one\ frontier} = \frac{DE}{DQ} \Big/ \frac{AC}{AP} \quad (1)$$

A ratio greater than one, equal to one, and less than one represents progress, no change, and regress in the technical efficiency of the DMU across two periods, respectively. The second component of the Malmquist index represents technical progress, which occurs due to shifts in the benchmark production frontier over time. In Figure 1, the reference point C in the first period shifts to B in the second period. Hence, the frontier-shift effect concerning the production point $(x_0, y_0)^1$ can be written as:

$$\pi_1 = \frac{AC}{AB} or \frac{AC}{AP} / \frac{AB}{AP} = \frac{Efficiency\ of (x_0,y_0)^1\ w.r.t\ period\ one\ frontier}{Efficiency\ of (x_0,y_0)^1\ w.r.t\ period\ two\ frontier} \quad (2)$$

Similarly, the frontier-shift effect concerning the production point $(x_0, y_0)^2$ can be expressed as:

$$\pi_2 = \frac{DF}{DE} or \frac{DF}{DQ} / \frac{DE}{DQ} = \frac{Efficiency\ of (x_0,y_0)^2\ w.r.t\ period\ one\ frontier}{Efficiency\ of (x_0,y_0)^2\ w.r.t\ period\ two\ frontier} \quad (3)$$

Fare et al. (1994) define the total frontier-shift effect as the geometric mean of $\pi_1$and π_2:

$$Frontier\ shift\ effects = \sqrt{\pi_1 \times \pi_2} \quad (4)$$

Like catch-up effects, a value greater than one, equal to one, and less than one represents progress, no change, and regress in frontier technology. Graphically, the Malmquist index (product of catch-up effects and frontier-shift effects) can be represented as:

$$MI = \frac{AP}{DQ}\sqrt{\frac{DF}{AC} \times \frac{DE}{AB}} \quad (5)$$

Chung et al. (1997) introduced the Malmquist-Luenberger productivity index (MLPI) to account for the presence of undesirable inputs and outputs. Subsequently, Oh (2010) developed the Global MLPI, which accounts for the classic infeasibility problem by incorporating negative data values. Further, Oh and Heshmati (2010) introduced a sequential MLPI that eliminates the possibility of spurious technical regress. Nevertheless, all of the above renditions of the Malmquist index are based on the traditional, black-box representation of production technology. Tone and Tsutsui (2014) describe a DEA-based, network-based specification of production structure. Subsequently, Bansal et al. (2022) have proposed the dynamic MLPI and the dynamic sequential MLPI, which are based on dynamic network production technology with an array of intermediate products and carryovers. Nevertheless, the dynamic MLPI is based on a short-term horizon that limits its application on a longitudinal dataset (Bansal et al., 2022). Hence, the present study employs the dynamic sequential MLPI to quantify TFP growth.

METHODOLOGY AND DATA

The study is operationalized through two panel datasets, each covering the period of 2005-2023. The BRICS dataset covers five countries (Brazil, Russia, India, China, and South Africa) and consists of 1,020 banks, aggregating to 9,326 bank-year observations. The European dataset spreads across 32 countries, including 27 EU members (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden), four EFTA nations (Iceland, Liechtenstein, Norway, Switzerland), and the United Kingdom. The sample covers 4,774 banks, aggregating 75,167 bank-year observations.

Owing to differences in regulatory structure, the sample is limited to commercial banks and does not include saving banks, cooperative banks, real estate and mortgage finance institutions, and other non-banking finance companies (NBFCs). Further, data, reported in US dollars, is collected on an unconsolidated basis and converted into a global standard format, ensuring compatibility across countries. Almost all the countries have witnessed a slew of mergers across the sample period, and hence, such banks are considered a separate cross-section pre-merger and a collective entity post-merger. Banks having less than three consecutive bank-year observations are excluded from the sample. The variables are winsorized at the 1st and 99th percentile to mitigate the impact of outliers.

Following Bansal et al. (2022), we employ a dynamic sequential Malmquist-Luenberger productivity index (DSMLPI) to model productivity change of commercial banks. In contrast to conventional MPI and MLPI models, which fail to consider the internal workings of the system and view a decision-making unit (DMU) as a black box, the DSMLPI adopts a comprehensive perspective on the production framework. First, the DSMLPI opens the traditional black box and unveils the inner workings of the production technology[1] by using a dynamic network production structure. This structure connects various divisions within the DMU vertically through intermediate activities and links multiple time periods through carryovers. Instead of treating the DMU as a black box, the DSMLPI offers a more nuanced understanding by accounting for the interconnectedness of different divisions and the continuity of operations across time periods. Further, while the dynamic Malmquist-Luenberger productivity index (DMLPI) is only suitable for a short-term horizon, the DSMLPI approach appropriately acknowledges the advancing trajectory of technology by encompassing all prior technologies within the construction of sequential frontier. The sequential production possibility set (PPS) at time t is defined as P¯_t=conv(P_1∪P_2∪………P_t), where t=(1,……,T), implying that P¯_t sequentially envelops all preceding technologies. Under a dynamic DEA specification, P¯_t can be represented as:

$$\bar{P}_t = \left(X_k^t, V_k^t, W_k^t, Y_k^t, U_k^t, C_{l_1 k}^t\right) | X_k^t \geq \sum_{\tau=1}^{t} \sum_{j=1}^{n} \lambda_{jk}^{\tau} X_{jk}^{\tau}, V_k^{\tau} \geq \sum_{\tau=1}^{t} \sum_{j=1}^{n} (\lambda_{jk}^{\tau} + \phi_{jk}^{\tau}) V_{jk}^{\tau}, W_k^t \leq \sum_{\tau=1}^{t} \sum_{j=1}^{n} \lambda_{jk}^{\tau} W_{jk}^{\tau}, Y_k^t \leq \sum_{\tau=1}^{t} \sum_{j=1}^{n} \lambda_{jk}^{\tau} Y_{jk}^{\tau}, U_k^t \geq \sum_{\tau=1}^{t} \sum_{j=1}^{n} \lambda_{jk}^{\tau} U_{jk}^{\tau}, C_k^t \leq \sum_{\tau=1}^{t} \sum_{j=1}^{n} \lambda_{jk}^{\tau} C_{jk}^{\tau},, C_k^{t-1} \geq \sum_{\tau=1}^{t} \sum_{j=1}^{n} \lambda_{jk}^{\tau} C_{jk}^{\tau-1}, \sum_{j=1}^{n} \lambda_{jk}^{t} Z_j^t = \sum_{j=1}^{n} \lambda_{jk+1}^{t} Z_j^t, k = 1, \dots, K-1, \sum_{\tau=1}^{t} \sum_{j=1}^{n} \lambda_{jk}^{\tau} = 1, \lambda_{jk}^{\tau}, \phi_{jk}^{\tau} \geq 0 \quad (6)$$

Here, $j \epsilon \{1, \dots, n\}$ is a set of n DMUs, $k \epsilon \{1, \dots, K\}$ is a set of K divisions, and t $\epsilon \{1, \dots, T\}$ is a set of T periods. X_k^t, V_k^t, and W_k^t are vectors for input, quasi-fixed input, and undesirable inputs of the k^{th} division in the t^{th} period, respectively. Further, Y_k^t, U_k^t, C_k^t, and Z_k^t are the vectors for desirable outputs, undesirable outputs, carryovers, and vertically-linked intermediate outputs of the k^{th} division in the t^{th} period, respectively. λ_k^t and ϕ_k^t are $(n \times 1)$ vectors to be estimated that facilitate the analysis of modelling a set of closely interconnected input-output measures wherein variables depict both strong and weak disposability. The above specification provides for the possibility of carryovers across time periods along with vertical production links among different divisions via intermediate outputs. Bansal et al. (2022) define the following vector specifications:

$$\mu_{ik}^t = \eta \times \max_{1 \leq j \leq n, 1 \leq \tau \leq t} \left| x_{ijk}^{\tau} \right|, \; i = (1, \dots, m) \; is \; a \; set \; of \; 'm' desirable \; inputs \quad (7)$$

$$\rho_{lk}^t = \min_{1 \leq j \leq n, 1 \leq \tau \leq t} w_{ljk}^{\tau} - \delta, \; l = (1, \dots, \xi) \; is \; a \; set \; of \; '\xi' undesirable \; inputs \quad (8)$$

$$v_{rk}^t = \min_{1 \leq j \leq n, 1 \leq \tau \leq t} y_{rjk}^{\tau} - \delta', \; r = (1, \dots, s) \; is \; a \; set \; of \; 's' desirable \; outputs \quad (9)$$

$$\omega_{pk}^t = \eta' \times \max_{1 \leq j \leq n, 1 \leq \tau \leq t} \left| u_{pjk}^{\tau} \right|, \; p = (1, \dots, \varrho) \; is \; a \; set \; of \; '\varrho' undesirable \; outputs \quad (10)$$

[1] The reader may refer Coelli et al. (2005) for a more detailed explanation of efficiency, technical change, and frontier shifts.

$$\gamma_{l_1k}^{t} = \min_{1\le j\le n, 1\le \tau\le t} c_{l_1jk}^{\tau} - \delta'', \ l_1 = (1,\dots,\varpi) \ is\ a\ set\ of\ '\varpi' desirable\ carryovers \quad (11)$$

$$\alpha_{l_1k}^{t} = \eta'' \times \max_{1\le j\le n, 1\le \tau\le t} \left|c_{l_1jk}^{\tau}\right|, \ l_1 = (1,\dots,\varpi) \ is\ a\ set\ of\ '\varpi' desirable\ carryovers \quad (12)$$

Here, η, η', η'', δ, δ', and δ'' are positive constants chosen in a manner such that the resultant direction vectors are positive:

$$\mu_{ik}^{t+1} < \mu_{ik}^{t}; \quad \rho_{lk}^{t+1} < \rho_{lk}^{t}; \quad v_{rk}^{t+1} < v_{rk}^{t}; \quad \omega_{pk}^{t+1} < \omega_{pk}^{t}; \quad \gamma_{l_1k}^{t+1} < \gamma_{l_1k}^{t}; \quad \alpha_{l_1k}^{t+1} < \alpha_{l_1k}^{t}$$

Let $f = (1,\dots,q)$ be a set of 'q' quasi-fixed inputs, and $g = (1,\dots,h)$ be a set of 'h' intermediate outputs. The dynamic sequential directional distance[2] functions can be calculated for $a, b \,\epsilon\, \{0,1\}$ via the following linear programming algorithms:

$$\overline{D}^{t+a}\left(X^{t+b}, V^{t+b}, W^{t+b}, Y^{t+b}, U^{t+b}, C^{dt+b}\right) = \max \beta_o^{a,b}$$

$$S.T. \sum_{\tau=1}^{t+a}\sum_{j=1}^{n} \lambda_{jk}^{\tau}\, x_{ijk}^{\tau} \le x_{iok}^{t+b} - \beta_o^{a,b}(x_{iok}^{t+b} + \mu_{ik}^{t+a})$$

$$\sum_{\tau=1}^{t+a}\sum_{j=1}^{n} (\lambda_{jk}^{\tau} + \phi_{jk}^{\tau}) v_{fjk}^{\tau} \le v_{fok}^{t+b})$$

$$\sum_{\tau=1}^{t+a}\sum_{j=1}^{n} \lambda_{jk}^{\tau}\, w_{ljk}^{\tau} \ge w_{lok}^{t+b} + \beta_o^{a,b}(w_{lok}^{t+b} - \rho_{lk}^{t+a})$$

$$\sum_{\tau=1}^{t+a}\sum_{j=1}^{n} \lambda_{jk}^{\tau}\, y_{rjk}^{\tau} \ge y_{rok}^{t+b} + \beta_o^{a,b}(y_{rok}^{t+b} - v_{rk}^{t+a})$$

$$\sum_{\tau=1}^{t+a}\sum_{j=1}^{n} \lambda_{jk}^{\tau}\, u_{pjk}^{\tau} \le u_{pok}^{t+b} - \beta_o^{a,b}(u_{pok}^{t+b} + \omega_{pk}^{t+a})$$

$$\sum_{\tau=1}^{t+a}\sum_{j=1}^{n} \lambda_{jk}^{\tau}\, c_{l_1jk}^{\tau} \ge c_{l_1ok}^{t+b} + \beta_o^{a,b}(c_{l_1ok}^{t+b} - \gamma_{l_1k}^{t+a})$$

$$\sum_{\tau=1}^{t+a}\sum_{j=1}^{n} \lambda_{jk}^{\tau}\, c_{l_1jk}^{\tau} \le c_{l_1ok}^{t+b-1} - \beta_o^{a,b}(c_{l_1ok}^{t+b-1} + \alpha_{l_1k}^{t+a-1})$$

$$\sum_{\tau=1}^{t+a}\sum_{j=1}^{n} \lambda_{jk}^{\tau}\, z_{gjk}^{\tau} = \sum_{\tau=1}^{t+a}\sum_{j=1}^{n} \lambda_{jk+1}^{\tau}\, z_{gjk}^{\tau}$$

$$\sum_{\tau=1}^{t+a}\sum_{j=1}^{n} \lambda_{jk}^{\tau} = 1$$

$$\beta_o^{a,b} \epsilon \mathrm{Z}; \lambda_{jk}^{\tau}, \phi_{jk}^{\tau} \ge 0 \quad (13)$$

Following the above linear equations, the DSMLPI across t and $t+1$ can be calculated as:

$$DSMLPI^{(t,t+1)} = \left(\frac{1+\overline{D}^{t}(X^{t},V^{t},W^{t},Y^{t},U^{t},C^{t})}{1+\overline{D}^{t}(X^{t+1},V^{t+1},W^{t+1},Y^{t+1},U^{t+1},C^{t+1})} \times \frac{1+\overline{D}^{t+1}(X^{t},V^{t},W^{t},Y^{t},U^{t},C^{t})}{1+\overline{D}^{t+1}(X^{t+1},V^{t+1},W^{t+1},Y^{t+1},U^{t+1},C^{t+1})}\right)^{\frac{1}{2}} \quad (14)$$

[2] Distance functions describe technology in a way that makes it possible to measure efficiency and productivity. The concept of a distance function is closely related to production frontiers. The basic idea underlying distance functions involves radial contractions and expansions that define these functions. Malmquist (1953) introduced the notion of distance functions.

Then above specification can be decomposed into technical efficiency change and technical change:

$$DSMLPI^{(t,t+1)} = \left(\frac{1+\bar{D}^{t}(X^{t},V^{t},W^{t},Y^{t},U^{t},C^{t})}{1+\bar{D}^{t+1}(X^{t+1},V^{t+1},W^{t+1},Y^{t+1},U^{t+1},C^{t+1})}\right) \times \left(\frac{1+\bar{D}^{t+1}(X^{t+1},V^{t+1},W^{t+1},Y^{t+1},U^{t+1},C^{t+1})}{1+\bar{D}^{t}(X^{t+1},V^{t+1},W^{t+1},Y^{t+1},U^{t+1},C^{t+1})} \times \frac{1+\bar{D}^{t+1}(X^{t},V^{t},W^{t},Y^{t},U^{t},C^{t})}{1+\bar{D}^{t}(X^{t},V^{t},W^{t},Y^{t},U^{t},C^{t})}\right)^{\frac{1}{2}} = EFFCH^{(t,t+1)} \times TECHCH^{(t,t+1)} \quad (15)$$

The ratio outside the square brackets represents the technical efficiency change component of the Malmquist index (EFFCH) across the period $(t)$and period $(t+1)$, while the ratio inside the square brackets represents the frontier shifts in technology (TECHCH) across two periods. A value greater than one for $EFFCH^{(t,t+1)}$ indicates that the bank moves closer to the benchmark production frontier in $t+1$. Further, $TECHCH^{(t,t+1)} > 1$ implies an autonomous outward shift of the production frontier. Nevertheless, $TECHCH^{(t,t+1)} < 1$, due to the restrictions imposed via the six constants (ηs and δs). Hence, $DSMLPI^{(t,t+1)} > 1$ indicates productivity growth, $DSMLPI^{(t,t+1)} = 1$, implies not productivity change, and $DSMLPI^{(t,t+1)} < 1$, indicates productivity regress across two time periods.

The distinction between inputs and outputs must be consistent with the functioning of the DMUs, industry norms, and the theory of firm behaviour (Sealey & Lindley, 1977). A significant argument revolves around determining the method for choosing inputs and outputs of a bank's production function, with each approach having distinct advantages and disadvantages. A significant reason for this debate is that banks and financial institutions, unlike manufacturing firms, do not have a proper demarcation between inputs and outputs (Cavallo & Rossi, 2002). A central focus of this debate lies in the treatment of deposits. While the production approach considers deposits as an output, the intermediation approach considers banks as a mediator of funds between depositors and borrowers, and subsequently, deposits are considered as input since banks repackage the deposit funds towards various income-generating activities (Fiorentino et al., 2006). Nevertheless, both approaches essentially treat the production technology as a "black box", which results in the conceptualization of production processes without detailed insights into the internal workings of each component. Following Bansal et al. (2022), we outline a three-stage production process of a commercial bank: (1) Stage I – Deposit generation process, (2) Stage II – Lending process, and (3) Stage III – Revenue generation process. The production technology is defined in terms of the workings of each division and connected via intermediate inputs and carryovers. In Stage I, it is hypothesized that the bank employs two variable inputs (labour and capital), along with a quasi-fixed input (equity capital) to generate deposits. The inclusion of equity capital as a netput is important to account for the differences in risk-return preferences of commercial banks (Oh, 2010). Further, we distinguish from the production and intermediation approaches by considering deposits as an intermediate product of the first division.

In Stage II, it is hypothesized that the bank uses deposits generated from the first stage to product three outputs – performing loans (desirable output), non-performing loans (undesirable output), and investments (desirable output). Nevertheless, the lending process is also impacted by the net profit (desirable carryover), and the non-performing loans (undesirable carryover) of the previous period (Bansal et al., 2022). Stage II analyses the "intermediation efficiency" of the production process. In Stage III, it is hypothesized that the bank employs loans and investments, along with loan loss provisions, as an additional choice input, to generate revenue in terms of net interest income. Nevertheless, banks also earn income from non-traditional business activities, in the form of non-interest income. It is pertinent to mention here that the non-performing loans from Stage II are not considered as an input in the Stage III, as banks do not earn revenue from non-performing loans. On its face, the three-staged dynamic production process employed in the study provides a comprehensive overview of the functioning of commercial banks, and is likely to provide reliable, risk-adjusted productivity scores for further analysis.

In addition, the physical input, quasi-fixed input, output, and carryover quantities are adjusted using the GDP price deflator[3] of each country to mitigate inflationary effects. Table 1 provides a detailed description of the variables. Figure 2 illustrates the three-stage, dynamic production process of a typical bank.

Table 1. Variable Description

Dynamic Sequential Malmquist-Luenberger Productivity Index

Variable	Acronym	Classification	Description
Total Factor Productivity Change	*TFPCH*	-	*Dynamic sequential Malmquist-Luenberger measure of TFP change*
Technical Efficiency Change	*EFFCH*	-	*Dynamic sequential Malmquist-Luenberger of TE change*
Technical Progress	*TECHCH*	-	*Dynamic sequential Malmquist-Luenberger measure of technical change*

Stage I: Deposit Generation Process

Variable	Acronym	Classification	Description
Labour	X_1	*Desirable input*	*Total staff expenses of full-time employees*
Capital	X_2	*Desirable input*	*Total operating cost incurred on assets*
Equity	F_1	*Quasi-fixed input*	*Equity capital*
Deposits	Y_1	*Desirable output (Division I)*	*Total interest expense on deposits, including customer deposits, bank deposits, and other long-term borrowings*

Stage II: Lending Process

Variable	Acronym	Classification	Description
Deposits	Y_1	*Desirable input (Division II)*	*Total interest expense on deposits, including customer deposits, bank deposits, and other long-term borrowings*
Non-Performing Loans $(t-1)$	C_1	*Undesirable carryovers*	*Total dollar value of gross non-performing loans* $(t-1)$
Net Profit $(t-1)$	C_2	*Desirable carryovers*	*Net profit before taxation* $(t-1)$
Performing Loans	Y_2	*Desirable output*	*Total dollar value of gross performing loans*
Non-Performing Loans (t)	U_1	*Undesirable output*	*Total dollar value of gross non-performing loans*
Investments	Y_3	*Desirable output*	*Total financial investments in stocks, bonds, debentures, and mutual funds*

[3] The GDP price deflator measures the annual change in GDP due to changes in price level. It is calculated as the ratio of GDP at current prices over GDP at constant prices:

$$GDP\ deflator = \frac{Nominal\ GDP}{Real\ GDP} \times 100$$

Table 1. Continued
Stage III: Revenue Generation Process

Variable	Acronym	Classification	Description
Performing Loans	Y_2	*Desirable input (Division III)*	*Total dollar value of gross performing loans*
Investments	Y_3	*Desirable input (Division III)*	*Total financial investments in stocks, bonds, debentures, and mutual funds*
Loan Loss Provisions	X_3	*Undesirable input*	*Total dollar value of provisioning for loan losses*
Non-interest income	Y_4	*Desirable output*	*Income earned from sources other than traditional banking, including fee and commission income, insurance income, trading income, and fair value gains*
Net Interest Income	Y_5	*Desirable output*	*Interest earned less interest expended*

Bank-Specific Efficiency Determinants

Variable	Acronym	Classification	Description
Size	*TA*	-	*Natural logarithm of average total assets*
Liquidity	*LADSTF*	-	*Liquid assets as a percentage of deposits and short-term funding*
Funding	*CDTFED*	-	*Customer deposits to total funding, excluding derivatives*
Earnings	*IIAIEA*	-	*Interest income to average interest-earning assets*
Information Technology	*IT*	-	*Natural logarithm of the total expenditure on information technology*
Research and Development	*RD*	-	*Natural logarithm of the total expenditure on research and development, including intangible assets other than goodwill*

Country-Specific Productivity Determinants

Variable	Acronym	Classification	Description
Real Interest Rate	*INT*	-	*Lending interest rates adjusted for inflation*
Inflation	*INF*	-	*Consumer price index (CPI) inflation*
GDP Growth	*GDPPC*	-	*Annual percentage growth in GDP per capita at constant prices*
Bank Concentration	*5-Bank*	-	*Bank concentration measure calculated as the share of banking assets held by the five largest banks in the country to total commercial banking assets*
Foreign Banks	*FBA*	-	*Share of commercial banking assets held by foreign banks in the country*
Bank Crisis	*Crisis*	-	*Banking crisis dummy*
COVID	*COVID*	-	*Dummy to account for the COVID-19 pandemic (2020-21, 2021-22)*

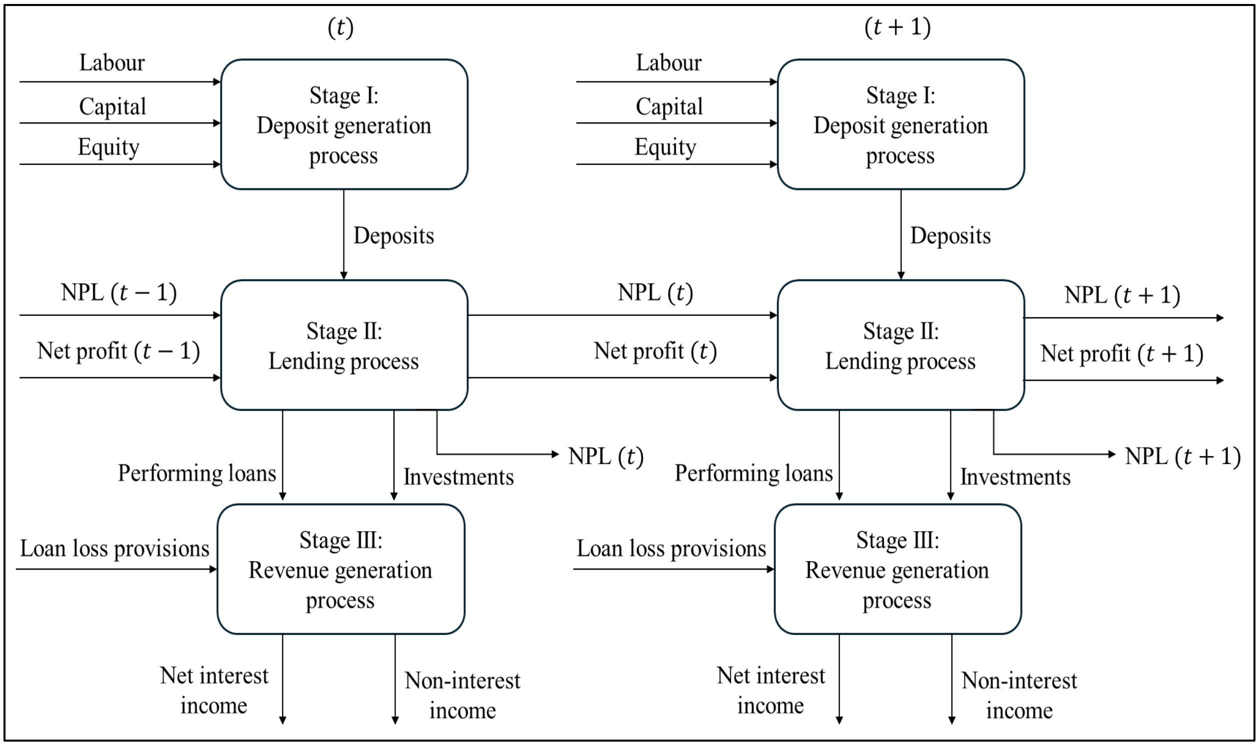

Figure 2. Three-stage Dynamic Production Model of a Commercial Bank

Further, the impact of IT investments in bringing about a change in total factor productivity is examined by developing the following regression model in log-log specification:

$$\ln(PDY)_{it} = \beta_0 + \beta_1 \ln(IT)_{it} + \beta_2 \ln(R\&D)_{it} + \beta_k Z_{kit} + \varepsilon_{it} \quad (16)$$

where:

$(PDY)_{it}$ TFP change, technical efficiency change, or frontier shifts Z_{kit} k^{th} regressors explaining TFP change.

Estimation of Equation (16) is conducted across the following lines. A static, fixed-effects regression provides a foundational understanding of the IT-productivity associations. However, a significant problem in productivity literature arises from the regressors being correlated with the error term, making the estimates biased and inconsistent. Three possible sources of endogeneity have been identified. First, reverse causality is possible as productivity associations are contemporaneous in nature. To this end, some reverse causality is accounted for by regressing current productivity scores on lagged bank-specific variables. Second, there may be productivity persistence, with previous productivity levels influencing current productivity levels. To account for the dynamic nature of productivity, lagged values have been incorporated in the regressions. However, some endogeneity also results from misspecification bias wherein some variables not included in the regression get subsumed in the error term. The parameter estimates become biased if these variables are correlated with the regressors. To this end, a two-step system generalized method of moments (GMM) estimator given by Blundell and Bond (1998) is adopted for controlling endogeneity. In the first step, the process differences the equation to remove bank-specific fixed effects. However, the possible correlation between the differenced error term and the lagged dependent variable creates a new bias. On the hypothesis that the differenced residuals are stochastic, independently distributed, and uncorrelated with each other, the following orthogonal moment conditions are identified to remove the correlation between the regressors and the error term:

$$E\left[Y_{i,t-s}\left(\Delta\varepsilon_{i,t}\right)\right] = 0 \quad t = 3, \dots\dots\dots, T;\ s \geq 2 \tag{17}$$

$$E\left[X_{i,t-s}\left(\Delta\varepsilon_{i,t}\right)\right] = 0 \quad t = 3, \dots\dots\dots, T;\ s \geq 2 \tag{18}$$

The above restrictions yield unbiased and consistent estimates (Roodman, 2009). Windmeijer's-corrected standard errors are reported that account for possible bias in small samples. Further, the application of system-GMM is validated using the Sargan test for over-identifying restrictions and the AR (2) test for no second-order autocorrelation.

RESULTS AND DISCUSSION

Table 2 presents the average, country-wise changes in TFP and its components across time. Across the sample period, the TFP change (TFPCH) is 1.211 for the BRICS nations, indicating that BRICS commercial banks gain 21.10 percent in terms of total factor productivity. TFP change can further be decomposed into changes in technical efficiency (EFFCH) and changes in technical progress (TECHCH). These values are 1.004 and 1.179, respectively, suggestive of the fact that technical progress has been a significant component in driving TFP gains vis-à-vis technical efficiency. This is an expected result for the developing banking sectors of BRICS, as these banking systems experience continuous innovation and diffusion of newer technologies, which shifts the production frontier outwards. In contrast, technical efficiency change has a negligible contribution to TFP change, indicating that BRICS banks can successively reduce their inputs by approximately 0.40 percent without influencing the existing output vector. Among the BRICS nations, the South Arican banking system depicts the highest TFP growth over the sample period, while Chinese banks have the lowest growth. In addition, the banking systems of Brazil and China depict average technical efficiency change (EFFCH) values of less than one (0.947 and 0.988, respectively), suggesting efficiency losses.

Further, the average TFP change for the European dataset is 1.485, indicating productivity gains of 48.50 percent over the sample period. However, in contrast to the BRICS nations, a significant proportion of TFP gains for the European banking sector is attributable to technical efficiency gains vis-à-vis technical progress (1.255 and 1.192, respectively). This is an expected result as the European banking sector is already operating on a technologically superior platform, and further advancements through frontier expansion are seldom possible. Hence, the focus of European banks inadvertently shifts to inefficiency reduction, which is illustrated by the movement of individual banks towards the constructed frontier. Within the European subset, the banking sectors of Norway, Spain, Poland, Latvia, and Germany depict the highest gains in total factor productivity in the sample period (as evidenced by average TFP change values of 1.906, 1.761, 1.703, 1.634, and 1.557 respectively). In contrast, the Finnish, Icelandic, and Lithuanian banking sectors depict the lowest gains in terms of TFP change (1.069, 1.013, and 1.027 respectively). In addition, the banking sectors of Bulgaria and Portugal depicts TFP losses. In contrast to BRICS nations, the European banking sector has witnessed a decrease in TFP and its components over the years.

Figure 3 illustrates the movements in TFP for the BRICS and European banking sectors across time. In addition, Figure 4 maps the average, country-specific TFP change for the two regions. The BRICS nations depict an increasing trend in TFP growth over the sample period. The average TFP change is greater than one for all years except 2010, perhaps on account of the global financial crisis (2008-2010).

Table 2. Average Country-Wise Change in TFP and its Components Across Time

Country	TFP Change (TFPCH)			Technical Efficiency Change (EFFCH)			Technical Progress (TECHCH)		
	2006-2011	2012-2017	2018-2023	2006-2011	2012-2017	2018-2023	2006-2011	2012-2017	2018-2023
Brazil	1.150	1.303	1.668	0.947	0.999	1.021	1.214	1.304	1.635
Russia	0.910	1.376	1.336	0.916	0.965	0.947	1.000	1.426	1.411
India	1.125	1.167	1.218	1.049	1.063	1.063	1.072	1.098	1.146
China	1.020	1.040	1.047	1.021	0.997	0.988	1.000	1.043	1.063
South Africa	1.082	1.214	1.662	1.765	1.082	1.199	1.028	1.000	1.023
BRICS	1.069	1.268	1.298	1.065	1.022	1.003	1.004	1.241	1.294
Austria	1.242	1.436	1.219	1.061	1.121	1.169	1.171	1.281	1.043
Belgium	2.018	1.452	1.136	1.109	1.221	1.091	1.823	1.189	1.041
Bulgaria	0.904	1.017	1.031	0.888	0.871	1.018	1.018	1.169	1.013
Croatia	1.471	1.484	1.534	1.104	1.116	1.122	1.332	1.330	1.367
Cyprus	1.857	0.966	1.180	1.801	0.889	1.181	1.031	1.087	1.000
Czech Republic	1.433	1.375	1.087	1.117	1.175	1.087	1.283	1.170	1.000
Denmark	1.103	1.290	1.238	1.103	1.066	1.068	1.000	1.210	1.159
Estonia	1.267	1.339	1.298	1.082	1.088	1.098	1.171	1.231	1.182
Finland	0.989	1.135	1.083	0.989	1.135	1.023	1.000	1.000	1.059
France	1.756	1.448	1.227	1.756	1.284	1.223	1.000	1.128	1.003
Germany	2.398	1.190	1.085	2.398	1.153	1.074	1.000	1.032	1.010
Greece	1.362	1.180	1.293	1.087	1.000	1.013	1.253	1.183	1.276
Hungary	0.950	1.491	1.338	0.959	1.267	1.269	1.000	1.177	1.054
Iceland	1.007	1.033	0.998	1.007	1.033	0.998	1.000	1.000	1.000
Ireland	1.188	1.394	0.911	0.932	0.755	0.779	1.275	1.847	1.171
Italy	1.174	1.264	1.267	0.803	1.143	0.969	1.462	1.106	1.308
Latvia	2.592	1.187	1.122	1.832	0.869	1.122	1.415	1.366	1.000
Liechtenstein	1.017	1.090	1.495	0.954	0.991	1.025	1.066	1.100	1.459
Lithuania	1.102	1.045	0.933	0.897	0.904	0.906	1.228	1.156	1.031
Luxembourg	1.721	1.803	1.151	1.445	1.679	1.151	1.191	1.074	1.000
Malta	1.683	1.772	1.089	1.292	1.126	1.081	1.305	1.574	1.007
Netherlands	1.629	1.231	1.095	1.049	1.042	1.095	1.553	1.181	1.000
Norway	2.730	1.767	1.221	2.731	1.441	1.176	1.000	1.226	1.044
Poland	1.679	1.718	1.712	1.004	1.053	1.303	1.672	1.632	1.314
Portugal	0.846	1.100	0.858	0.725	0.772	0.724	1.167	1.425	1.185
Romania	1.012	1.316	1.186	0.946	1.043	1.116	1.073	1.262	1.063
Slovakia	0.924	1.271	1.321	0.924	1.007	1.127	1.000	1.262	1.172
Slovenia	1.195	1.241	1.118	0.944	0.999	0.991	1.266	1.242	1.128
Spain	2.382	1.455	1.445	2.382	1.455	1.165	1.000	1.000	1.243
Sweden	0.930	1.555	1.298	0.827	1.230	1.191	1.125	1.264	1.092
Switzerland	1.710	1.016	0.991	1.583	0.987	0.991	1.080	1.029	1.000
United Kingdom	1.277	1.371	1.531	1.196	1.134	1.676	1.037	1.209	1.510
EU	1.736	1.386	1.334	1.554	1.117	1.094	1.117	1.241	1.219

Note: The above table depicts the average country-wise changes in TFP and its components across time for the BRICS and European banking systems. All indices are calculated from 2006 (first year omitted).

Since 2010, the BRICS banking sector has been continuously characterized by productivity increases. Further, the European banking sector witnessed productivity gains during the earlier years (2006-2009), reaching a maximum of 1.725. In line with the BRICS nations, productivity growth decreased in 2010 on account of the crisis. Nevertheless, the European banking sector portrays a decrease in TFP growth in the later years (2016-2023). Further, from 2016-2021, the BRICS nations have continuously outperformed the European nations in terms of productivity growth. This reinforces the notion of productivity catch-up and convergence among the BRICS and the Europe banking sectors. In addition, the diminishing growth rates of the European banking sector underline the presence of a catch-up effect.

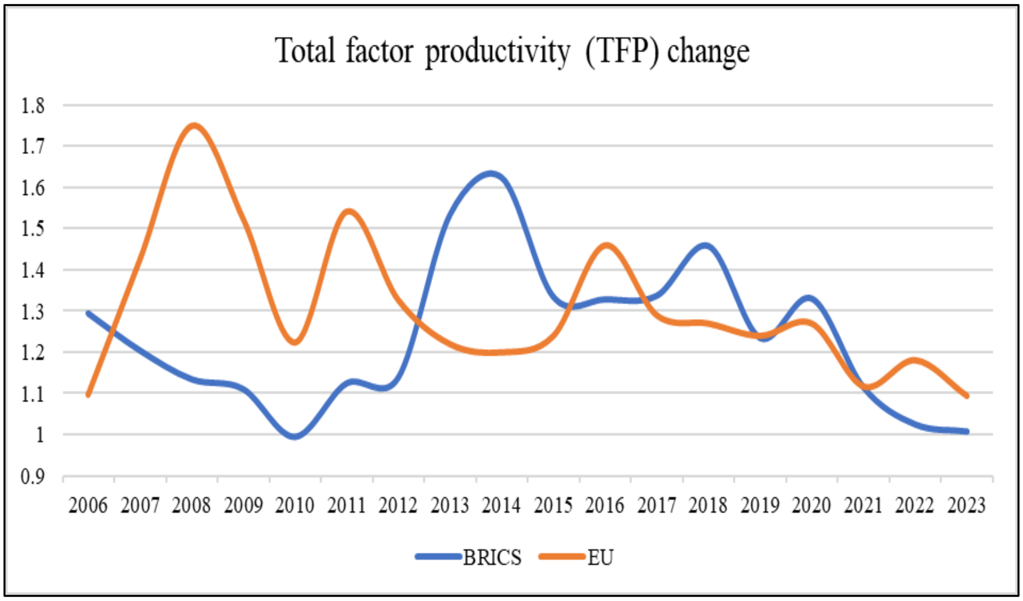

Figure 3. TFP Movements Across Time (2006-2023)
Note: The above figure illustrates the changes in TFP of the BRICS and European banking systems across time. Index calculation starts from 2006 (first year omitted).

Further, Figure 5 depicts the technical efficiency movements of the two geopolitical regions across time. In addition, Figure 6 maps the average, country-specific TE change for the two regions. Technical efficiency change is defined in terms of the ability of the firm to use the current technology to minimize input usage for producing the same output vector. Hence, it is conceivable for DMUs to perform efficiently even when there are no changes in the production technology. Such improvements are characterized by the movement of individual DMUs towards the best-practice frontier.

For the BRICS nations, TE change forms a marginal component of TFP change. Since 2011, the average technical efficiency index has hovered above one, suggestive of the fact that there have neither been efficiency improvements nor efficiency losses. In contrast, the average technical efficiency change is highly variable for European commercial banks over the years. The European banking sector has constantly witnessed a decline in technical efficiency, suggestive of movements of European banks away from the benchmarks.

Figure 7 graphically illustrates the technical progress of the two geopolitical regions over the sample period, while Figure 8 maps the patterns of technical change. Technical changes[4]

[4] It must be noted that technical change may not always be technological (introduction of a new technology) but can also be managerial, organizational, or result from a factor that is entirely outside the control of a DMU (for instance, reduction in input prices, ease in regulations, reduction in competition).

are characterized by the improvements (or regressions) in production technology that lead to expansion (contraction) of the production frontier.

The BRICS nations have witnessed moderate frontier expansions since 2010. This is an expected result as BRICS commercial banks, utilizing the superannuated technology of the leader countries, can produce more outputs from the same inputs, expanding the production frontier outwards. On the other hand, European banks experienced a faster rate of technical progress since 2011.

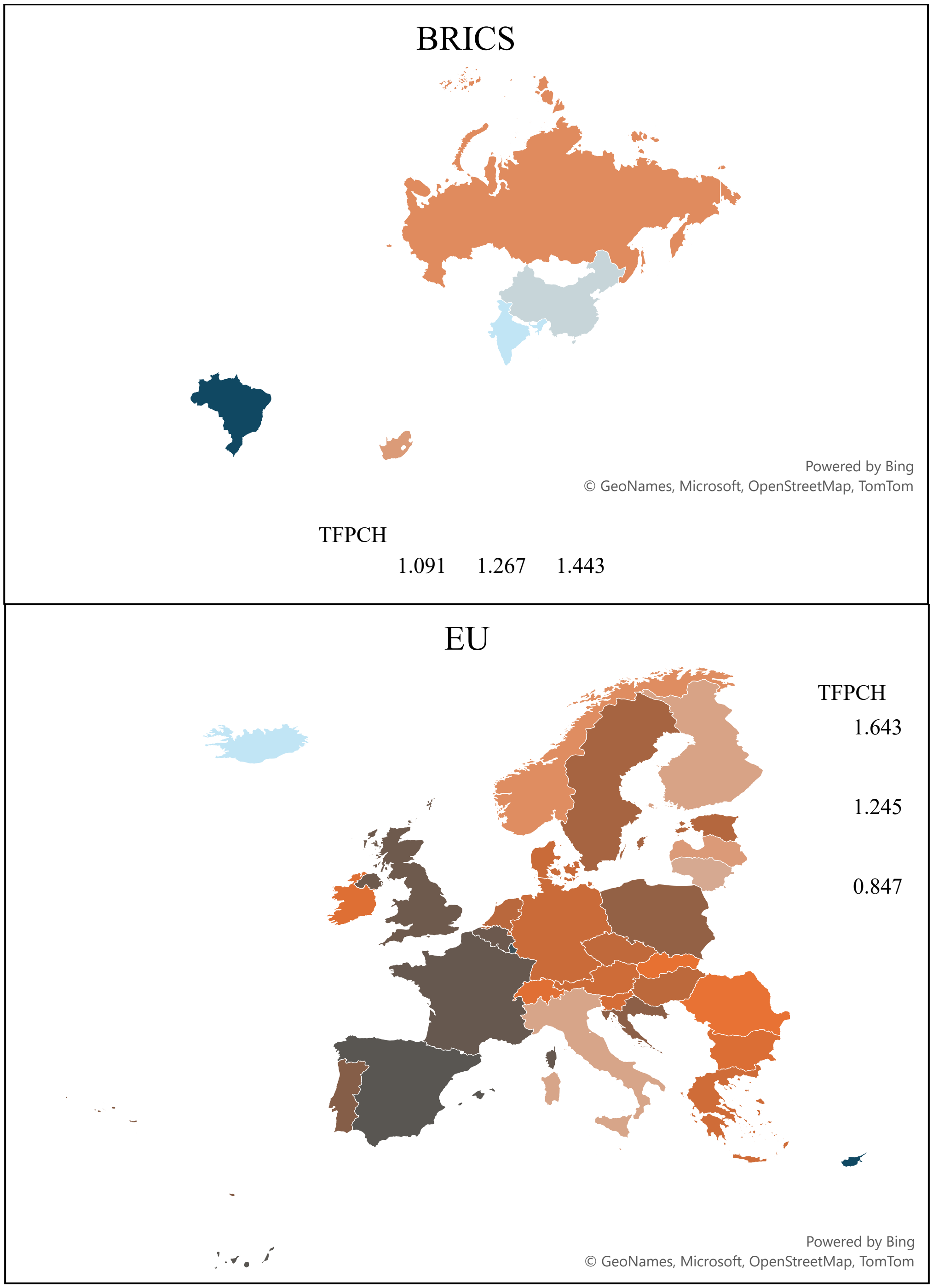

Figure 4. Pattern of TFP Change in BRICS and European Banking Systems

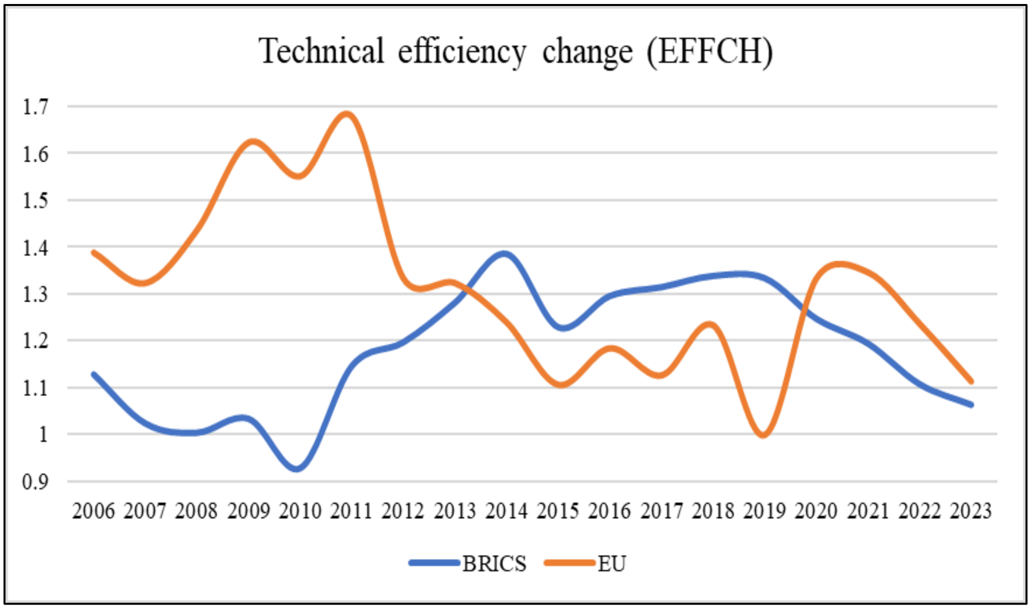

Figure 5. Technical Efficiency Movements Across Time (2006-2023)
Note: The above figure illustrates the changes in technical efficiency of the BRICS and European banking systems across time. Index calculation starts from 2006 (first year omitted).

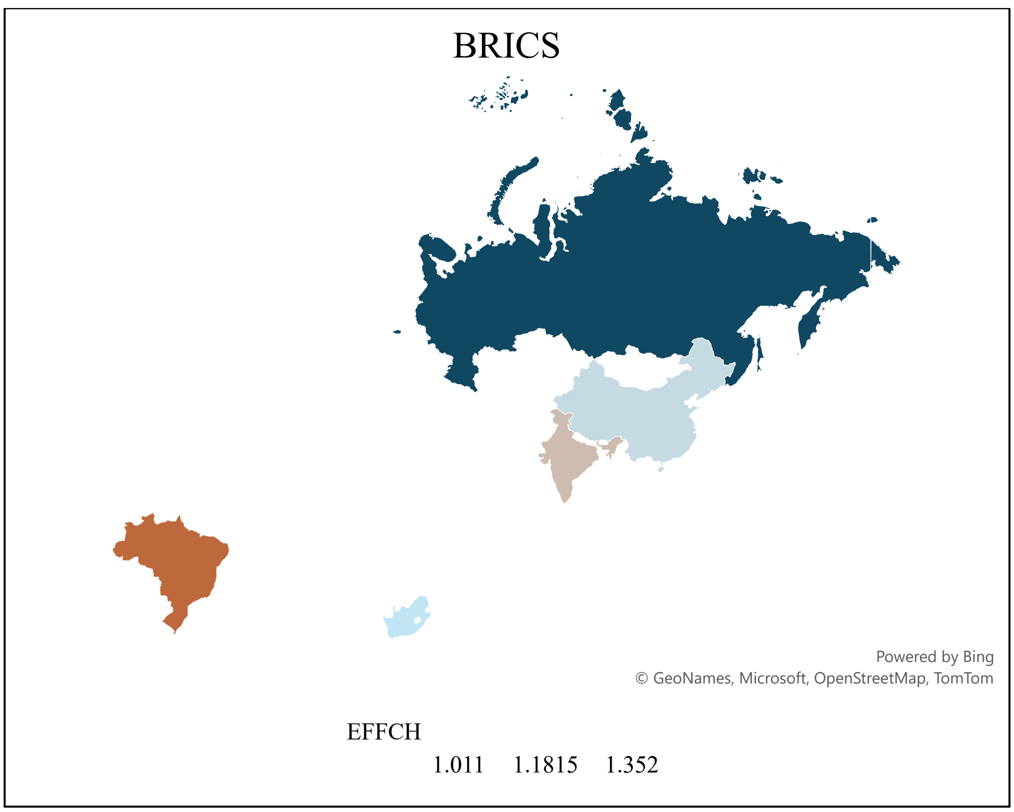

Figure 6. Pattern of TE Change in BRICS and European Banking Systems

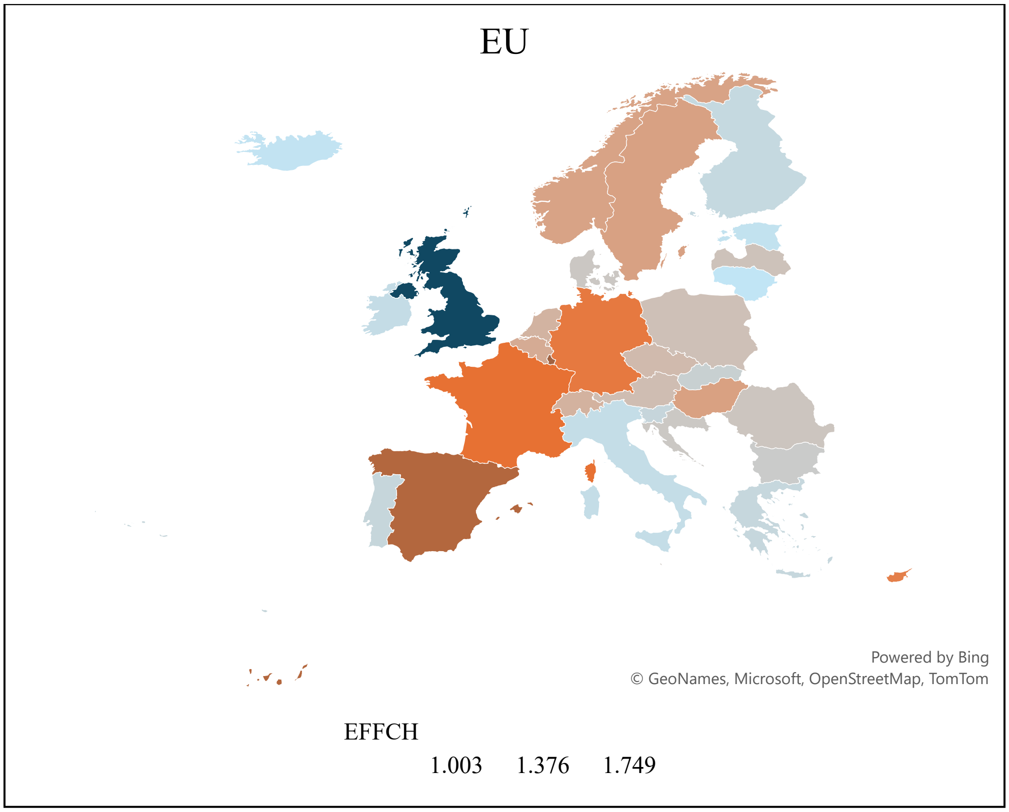

Figure 6. Continued

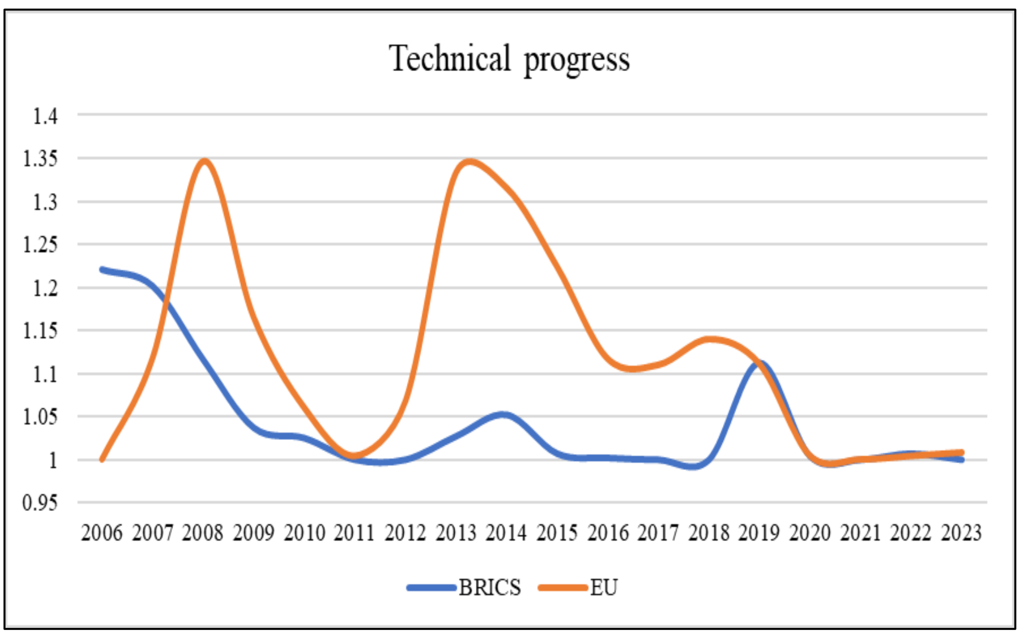

Figure 7. Technical Progress Across Time (2006-2023)

Note: The above figure illustrates the changes in the technical progress of the BRICS and European banking systems across time. Index calculation starts from 2006 (first year omitted).

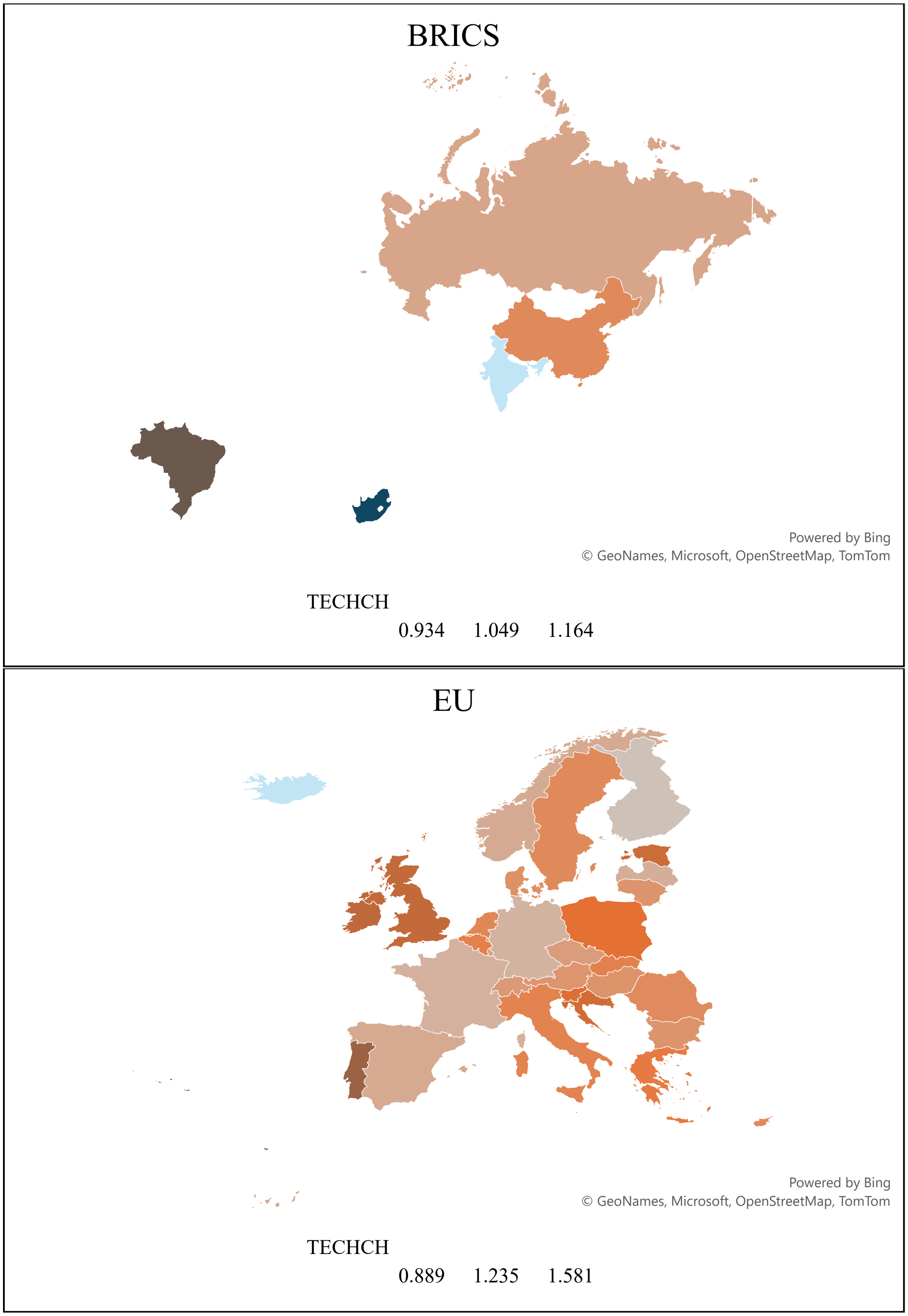

Figure 8. Pattern of Technical Change in BRICS and European Banking Systems

IT-TFPCH ASSOCIATIONS

Table 3 accentuates the IT-TFPCH associations through static (fixed effects) and dynamic (system GMM) models. Subsequently, Table 4 contains an array of diagnostic tests for model specification. Two diagnostic tests are conducted for static models. The Hausman χ^2 statistic exceeds its critical value at the threshold significance levels for both geopolitical regions, indicating the preference for using the fixed effects model over random effects. Further, the Breusch-Pagan Lagrange multiplier (LM) test is initiated to check cross-sectional interdependence. Under the null hypothesis that the residuals across cross-sections are not correlated, the LM test is distributed as a χ^2 statistic. The null is not rejected for both regressions, indicating that cross-sectional interdependence is not a significant impediment in fixed-effects estimation[5]. Further, three tests are conducted to check the suitability of a two-step system GMM estimation. The Hansen's J statistic is insignificant in both models, suggesting that over-identifying restrictions in a system GMM model is valid. Further, the p-values derived from the AR (1) and AR (2) tests are significant and insignificant, respectively, for both banking sectors, which further lends credibility to the use of two-step system GMM estimation as a technique for handling dynamic panel data.

It is observed that IT investments are positively associated with TFP growth for the BRICS banking sectors in static and dynamic models (0.131 and 0.134, respectively). This is an expected result as IT investments improve production and service delivery processes, reduce waste, and ultimately enhance the factor productivity of BRICS banks. It is essential to note that the measure of TFP growth employed in this study provides an overview of productivity in its entirety, instead of input-specific (or output-specific) productivity. Hence, attributing the impact of productivity determinants on a specific input (or output) becomes a tedious task in second-stage regressions. On its face, the gains in TFP change from IT may result from the fact that IT investments can influence (1) Capital productivity (in terms of benefits derived from superannuation, the introduction of newer technologies, and innovations); (2) Labour productivity (in terms of positive effects on human capital through reduced wastage and increased collaboration). In the same vein, IT investments can positively influence bank output, which consequently translates into higher TFP growth. Nevertheless, R&D spending has no bearing on TFP change for BRICS banks, suggesting that investment in innovative technologies has not resulted in productivity gains.

In contrast, IT exerts a negative influence on the TFP of European commercial banks, indicating that such investments translate into productivity losses. A significant reason emerges from the fact that the developed banking markets of Europe already operate on a high technological level, and further investments in elementary IT solutions are of little use to individual banks. Further, intra-industry duplication of technologies is another impediment that does not lead to the creation of a sustainable competitive advantage from IT. However, positive productivity returns are witnessed from R&D spending for European commercial banks (positive and significant coefficients of 0.138 and 0.026 for static and dynamic models, respectively), suggestive of the fact that investing in innovative solutions might be a way forward for these banks in a bid towards enhancing the TFP ratios.

IT-EFFCH ASSOCIATIONS

Table 5 accentuates the impact of IT-specific variables on the first component of TFP growth: changes in technical efficiency (EFFCH) for the two geopolitical regions. Table 6 contains the associated diagnostic tests. Similar to the previous findings, the suitability of the fixed-effects estimation is advocated from significant values of the Hausman χ^2 statistic. Further, the LM test signifies the

[5] Baltagi (2008) advocate that the problem of cross-sectional interdependence is more significant in case of macro panels (long time-series data with few cross-sections) than micro panels (many cross-sections and few years).

Table 3. Impact of IT Investments on TFP Change (TFPCH)

IT-Specific Determinants

	BRICS		EU	
Variables	**FE**	**GMM**	**FE**	**GMM**
IT	*0.131*** *(0.061)*	*0.134**** *(0.026)*	*-0.039** *(0.018)*	*-0.037**** *(0.007)*
RD	*0.018* *(0.029)*	*0.067* *(0.119)*	*0.138**** *(0.040)*	*0.026*** *(0.012)*

Bank-Specific Determinants

	BRICS		EU	
Variables	**FE**	**GMM**	**FE**	**GMM**
TFP (-1)	- -	*1.613**** *(0.337)*	- -	*0.774**** *(0.152)*
TA	*-0.037**** *(0.013)*	*-0.096**** *(0.042)*	*0.331**** *(0.160)*	*0.226*** *(0.109)*
LADSTF	*0.007* *(0.013)*	*0.011* *(0.009)*	*0.019**** *(0.004)*	*0.040* *(0.069)*
CDTFED	*0.001* *(0.007)*	*-0.005**** *(0.001)*	*0.006* *(0.028)*	*0.064* *(0.095)*
IIAIEA	*-0.016**** *(0.006)*	*-0.018**** *(0.003)*	*-0.002* *(0.008)*	*0.026* *(0.029)*

Country-Specific Determinants

	BRICS		EU	
Variables	**FE**	**GMM**	**FE**	**GMM**
INT	*-0.013*** *(0.006)*	*0.029* *(0.048)*	*-0.018**** *(0.007)*	*-0.031**** *(0.014)*
INF	*-0.009**** *(0.003)*	*-0.016**** *(0.007)*	*-0.062* *(0.095)*	*-0.047* *(0.088)*
GDPPC	*0.034* *(0.067)*	*0.019**** *(0.004)*	*0.011*** *(0.005)*	*0.054*** *(0.026)*
5-Bank	*-0.004**** *(0.001)*	*-0.022** *(0.011)*	*-0.005**** *(0.002)*	*-0.067* *(0.054)*
FBA	*0.025**** *(0.011)*	*0.069* *(0.095)*	*-0.015* *(0.017)*	*-0.004* *(0.012)*
Crisis	*0.029* *(0.063)*	*0.665* *(0.905)*	*-0.295**** *(0.047)*	*0.667**** *(0.162)*
COVID	*-0.004**** *(0.002)*	*-0.002** *(0.001)*	*-0.003*** *(0.001)*	*-0.002* *(0.002)*

Note: *The above table depicts the influence of IT investments in bringing a change in total factor productivity (TFP) of BRICS and European banks. The regressions are conducted through static (fixed effects) and dynamic (two-step system GMM) models. Robust standard errors in parentheses for fixed effects models. Windmeijer's standard errors are in parentheses for system GMM models. All models contain unreported country-fixed effects. ***, **, and * indicate significance at 1, 5, and 10 percent, respectively.*

Table 4. Diagnostic Tests (TFPCH)

	BRICS		EU	
Test Description	**FE**	**GMM**	**FE**	**GMM**
Hausman χ^2	27.638***	-	27.934***	-
P-value	0.004	-	0.009	-
Breusch Pagan LM	16.427	-	15.655	-
P-value	0.124	-	0.141	-
Hansen J	-	16.223	-	8.927
P-value	-	0.147	-	0.532
AR (1) P-value	-	0.014	-	0.092
AR (2) P-value	-	0.953	-	0.886

absence of a panel correlation between residuals. The validity of GMM estimation is further corroborated through the insignificant values of Hansen's statistic and AR (2) test for no second-order autocorrelation.

For the BRICS nations, IT investments positively correlate with TE change in the fixed effects model. Nevertheless, the coefficient becomes insignificant when a more robust dynamic estimation is employed, suggestive of the fact that IT investments play no role in the ability of a firm to operate closer to the productivity frontier. On its face, even though IT investments result in productivity gains for the BRICS banking sector, the gains do not augment the ability of a bank to reduce its input for producing the same output vector. Further, R&D spending exerts a positive impact on TE change. However, the coefficients are insignificant at the threshold significance levels.

In contrast, IT investments positively associate with TE change for European commercial banks (as evidenced by significant coefficients of 0.016 and 0.047 from the static and dynamic models, respectively). This observation points to the inference that European banks can leverage IT investments to achieve frontier-level performance by reducing technical inefficiencies. In addition, R&D spending positively influences TE change for European banks (significant coefficients of 0.069 and 0.014 in fixed and dynamic models, respectively). Overall, it is observed that IT-specific variables are a crucial determinant in influencing the ability of the European banking market to reduce technical inefficiencies and operate near or on the constructed frontier.

Further, the coefficient of the lagged dependent variable is positive and statistically significant for both regional blocs, indicating a favourable TE persistence. In addition, bank size (TA) exerts a negative impact on TE change for the BRICS nations and a positive impact on the European nations, indicative of scale diseconomies for the former and scale economies for the latter. Bank liquidity, proxied as the proportion of liquid assets to deposits and short-term funding ($LADSTF$), positively associates with TE change for both geopolitical regions. In contrast, non-performing loans (NPL) reduce the ability of both sets of commercial banks to operate near the productivity frontier. This is an expected result as bad loans entail increased supervisory and monitoring costs, enhanced provisioning, and managerial uncertainty, resulting in lower TE ratios. Further, increased reliance on customer deposits as a source of funding ($CDTFED$) reduces TE ratios of BRICS commercial banks but has no significant impact on the ratios of European commercial banks. In addition, interest income as a percentage of interest-earning assets ($IIAIEA$) positively associates with TE change for European banks, suggestive of the fact that higher interest yields from loans enhance technical efficiency.

Concerning country-specific determinants, real interest rates (INT) correlate negatively with TE change for both regional blocs. Additionally, higher inflation (INF) is associated with TE losses for

BRICS commercial banks. Further, higher concentration ratios cause TE losses for both regional subsets, indicative of the fact that increased concentration hinders the movement of banks toward the productivity frontier.

Table 5. Impact of IT Investments on Technical Efficiency Change (EFFCH)

IT-Specific Determinants

Variables	BRICS FE	BRICS GMM	EU FE	EU GMM
IT	*0.014*	*0.031*	*0.016****	*0.047****
	(0.010)	*(0.029)*	*(0.003)*	*(0.018)*
RD	*0.021*	*0.010*	*0.069****	*0.014**
	(0.018)	*(0.064)*	*(0.024)*	*(0.007)*

Bank-Specific Determinants

Variables	BRICS FE	BRICS GMM	EU FE	EU GMM
EFFCH (-1)	-	*0.716****	-	*0.638****
	-	*(0.294)*	-	*(0.114)*
TA	*-0.222****	*-0.349****	*0.178****	*0.162****
	(0.106)	*(0.061)*	*(0.041)*	*(0.033)*
LADSTF	*0.007****	*0.006****	*0.002****	*0.004*
	(0.002)	*(0.002)*	*(0.001)*	*(0.018)*
CDTFED	*-0.005***	*-0.008*	*0.003*	*0.029*
	(0.002)	*(0.005)*	*(0.007)*	*(0.047)*
IIAIEA	*-0.014*	*0.027****	*0.099****	*0.104****
	(0.009)	*(0.012)*	*(0.037)*	*(0.023)*

Country-Specific Determinants

Variables	BRICS FE	BRICS GMM	EU FE	EU GMM
INT	*-0.012****	*-0.039**	*-0.063****	*-0.076****
	(0.005)	*(0.019)*	*(0.008)*	*(0.021)*
INF	*-0.027*	*-0.014***	*-0.014*	*-0.095*
	(0.079)	*(0.006)*	*(0.023)*	*(0.196)*
GDPPC	*0.005*	*0.071*	*0.009****	*0.014*
	(0.097)	*(0.092)*	*(0.003)*	*(0.092)*
5-Bank	*-0.007****	*-0.011****	*-0.001*	*-0.023*
	(0.002)	*(0.004)*	*(0.008)*	*(0.029)*
FBA	*0.004*	*0.010*	*-0.026****	*-0.006****
	(0.024)	*(0.073)*	*(0.011)*	*(0.001)*
Crisis	*-0.073*	*-0.771*	*-0.054***	*0.109****
	(0.293)	*(1.624)*	*(0.025)*	*(0.053)*
COVID	*-0.001*	*-0.004*	*-0.003*	*-0.001*
	(0.097)	*(0.029)*	*(0.627)*	*(0.004)*

Note: *The above table depicts the influence of IT investments in bringing a change in the technical efficiency of BRICS and European banks. The regressions are conducted through static (fixed effects) and dynamic (two-step system GMM) models. Robust standard errors in parentheses for fixed effects models. Windmeijer's standard errors are in parentheses for system GMM models. All models contain unreported country-fixed effects. ***, **, and * indicate significance at 1, 5, and 10 percent, respectively.*

Table 6. Diagnostic Tests (EFFCH)

	BRICS		EU	
Test Description	**FE**	**GMM**	**FE**	**GMM**
Hausman χ^2	*31.627******	-	*21.600**	-
P-value	*0.000*	-	*0.073*	-
Breusch Pagan LM	*17.634*	-	*15.319*	-
P-value	*0.137*	-	*0.194*	-
Hansen J	-	*2.627*	-	*3.774*
P-value	-	*0.334*	-	*0.317*
AR (1) P-value	-	*0.000*	-	*0.000*
AR (2) P-value	-	*0.595*	-	*0.611*

IT-TECHCH ASSOCIATIONS

Theoretically, technological progress (regress) emancipates from events that expand (contract) the productivity frontier. Such events can shift the frontier outwards, allowing DMUs to produce more output from the same level of inputs, indicating technical progress. On the other hand, technical contraction causes a reduction in productivity, indicating technical regress. Table 7 tabulates the IT-TECHCH associations for the BRICS and European banking markets, and Table 8 contains the necessary diagnostic tests. For static models, the Hausman test reveals no evidence supporting the null hypothesis (no correlation between the unobserved, time-invariant heterogeneity and independent variables), indicating that fixed effects estimation is a suitable model. Further, in line with the previous estimations, the Breusch-Pagan LM statistic is insignificant, implying no cross-sectional dependence. Considering dynamic models, the AR (1) test statistic for first-order autocorrelation is significant at threshold levels, indicating the presence of a dynamic structure of the panel data. More importantly, the p-value of the AR (2) test is greater than 0.10, further reinforcing the use of the two-step system GMM. Further, the Hansen test reveals that over-identifying restrictions in the GMM model are valid for both geopolitical regions (p-values of 0.298 and 0.176 for the BRICS and European nations, respectively).

The lagged dependent variable is significant and positive for both regional blocs, implying the persistence of technical progress. Coming to the variables of interest, IT investments positively correlate with technical progress for the BRICS banking system (as evidenced by significant coefficients of 0.068 and 0.022 in static and dynamic models, respectively). On its face, investment in information technology shifts the productivity frontier outwards and results in technical progress. When analysed in association with the findings in the previous subsection, the results demonstrate that a significant proportion of TFP growth from IT investments is by virtue of technical progress (shift of the production frontier) vis-à-vis TE change (movement towards the productivity frontier). Further, R&D spending facilitates technical progress for the BRICS nations.

In contrast, IT is not significantly associated with the technical change of European commercial banks (as evidenced by positive but insignificant coefficients of 0.163 and 0.077 for static and dynamic models, respectively). In simple words, investments in IT are unable to shift the productivity frontier outwards. This can be due to two reasons. First, European banks invest a significant proportion of their IT budgets in supporting innovations (instead of breakthrough innovations that significantly disrupt the production processes). Second, most European banking systems already face a technologically developed frontier. As a result, further expansions to the frontier are seldom possible. These findings, when corroborated with the results of the previous subsection, suggest that European commercial banks, in general, rely upon improvements in technical efficiency as a source of productivity growth vis-à-vis technical progress. Further, innovative investments in the form of high R&D spending are also unable to improve technical production.

In addition, economies of scale are witnessed for European commercial banks, while BRICS commercial banks experience diseconomies of scale. Increased liquidity enhances technical progress for BRICS and European banking systems. The banking crisis resulted in the contraction of the productivity frontier for both banking systems. Further, higher inflation results in technical contractions.

Table 7. Impact of IT investments on technical progress (TECHCH)

IT-Specific Determinants

	BRICS		EU	
Variables	**FE**	**GMM**	**FE**	**GMM**
IT	*0.068** *(0.033)*	*0.022**** *(0.010)*	*0.163* *(0.324)*	*0.077* *(0.073)*
RD	*0.002* *(0.002)*	*0.037* *(0.095)*	*0.195* *(0.240)*	*0.065* *(0.608)*

Bank-Specific Determinants

	BRICS		EU	
Variables	**FE**	**GMM**	**FE**	**GMM**
TECHCH (-1)	- -	*0.376**** *(0.110)*	- -	*0.936**** *(0.289)*
TA	*-0.329**** *(0.104)*	*-0.169**** *(0.068)*	*0.033**** *(0.009)*	*0.340**** *(0.100)*
LADSTF	*0.008* *(0.011)*	*0.002* *(0.007)*	*0.095* *(0.122)*	*0.096* *(0.702)*
CDTFED	*-0.004**** *(0.001)*	*-0.007* *(0.029)*	*0.031**** *(0.012)*	*0.037**** *(0.009)*
IIAIEA	*0.004* *(0.007)*	*0.010**** *(0.002)*	*0.037* *(0.907)*	*0.137* *(0.606)*

Country-Specific Determinants

	BRICS		EU	
Variables	**FE**	**GMM**	**FE**	**GMM**
INT	-0.004* (0.002)	-0.010*** (0.003)	-0.036*** (0.004)	-0.077*** (0.026)
INF	-0.098*** (0.027)	-0.016*** (0.007)	-0.032* (0.015)	-0.038*** (0.013)
GDPPC	0.009 (0.010)	0.032 (0.050)	0.017 (0.089)	0.023 (0.037)
5-Bank	-0.011*** (0.004)	-0.061*** (0.024)	-0.004 (0.061)	-0.022*** (0.006)

Table 7. Continued
Country-Specific Determinants

	BRICS		EU	
Variables	**FE**	**GMM**	**FE**	**GMM**
FBA	0.002 (0.007)	0.002 (0.009)	-0.001 (0.016)	-0.001 (0.097)
Crisis	-0.011* (0.005)	-0.021*** (0.007)	-0.033 (0.019)	-0.018** (0.008)
COVID	-0.002*** (0.001)	-0.008* (0.004)	-0.003*** (0.001)	-0.002 (0.005)

Note: *The above table depicts the influence of IT investments on the technical progress of BRICS and European banks. The regressions are conducted through static (fixed effects) and dynamic (two-step system GMM) models. Robust standard errors in parentheses for fixed effects models. Windmeijer's standard errors are in parentheses for system GMM models. All models contain unreported country-fixed effects. ***, **, and * indicate significance at 1, 5, and 10 percent, respectively.*

Table 8. Diagnostic Tests (TECHCH)

	BRICS		EU	
Test Description	**FE**	**GMM**	**FE**	**GMM**
Hausman χ^2	*27.938****	-	*34.927****	-
P-value	*0.000*	-	*0.000*	-
Breusch Pagan LM	*19.299*	-	*18.021*	-
P-value	*0.171*	-	*0.246*	-
Hansen J	-	*1.997*	-	2.666
P-value	-	*0.298*	-	*0.176*
AR (1) P-value	-	*0.002*	-	*0.006*
AR (2) P-value	-	*0.267*	-	*0.637*

CONCLUSION AND POLICY RELEVANCE

The banking sector has been one of the early adopters of information technology, and IT-led productivity growth has been a primary driver of the sector's success. Banks have used IT to automate back-office operations, improve customer service, and enhance risk management, resulting in increased efficiency and productivity. IT solutions such as mobile banking, online banking, and digital payments have revolutionized how customers interact with banks, making banking more accessible and convenient. Moreover, IT has enabled banks to offer personalized services, tailor products to customer needs, and improve customer satisfaction, resulting in increased loyalty and revenue growth. However, IT-led productivity growth has also brought challenges, such as cybersecurity risks and the need for constant innovation to keep pace with changing customer demands. The implications of the productivity paradox are significant, as productivity growth is essential for economic growth and competitiveness. Furthermore, the paradox may result in a misallocation of resources, as businesses may continue to invest in IT without realizing productivity gains, leading to reduced profitability and competitiveness.

This paper highlights the IT-productivity associations for the BRICS and European commercial banking sectors. Productivity growth is quantified in terms of changes in TFP. The Malmquist productivity index is employed for calculating TFP change, and the same has been utilized for disintegrating TFP change into TE change and technical change. Productivity determinants (which include a measure of IT investments and R&D spending) are analysed using static (fixed effects) and dynamic (two-step system GMM) models. The findings provide sufficient evidence against the productivity paradox as both regional blocs enjoy IT-fuelled productivity growth. Nevertheless, how IT influences different productivity components is critical in understanding IT-productivity associations. Further, these associations vary across the level of banking sector development, providing insight into how IT resources can explain productivity differences across nations.

Examining the impact of IT on TFP components yields interesting observations. It is observed that a significant proportion of IT-fuelled TFP growth originates in terms of expansion of the productivity frontier (technical progress) instead of a movement towards the productivity frontier (TE change). On the one hand, this is an expected result as the banks of the developing nations of BRICS continue to utilize the superannuated technology of leader countries (in addition to their own innovations), which enhances the technical ratios and shifts the productivity frontier outwards. On the other hand, the absence of IT-fuelled TE change is of note for BRICS commercial banks, as such an observation indicates that IT investments have not enhanced their ability to produce an input-minimizing output vector. This serves as a caution for banks already operating on lower productivity levels, as such banks are already distant in achieving frontier-level performance. As a result, it can be inferred that IT adoption in the BRICS commercial banking sector has widened the technology gap.

In the same vein, European commercial banks also enjoy IT-led productivity growth, as evidenced by the positive associations of IT and R&D spending with TFP change. Nevertheless, a significant proportion of TFP growth is explained in terms of the movements of individual firms along the productivity frontier. This illustrates that IT investments have not resulted in frontier expansions for the European banks. This can be due to a variety of reasons. First, a significant proportion of IT investments have been evolutionary (rather than revolutionary) in nature. Further, these innovations are easily duplicated by the competitors, which erodes competitive advantage. Second, the developed banking sector of Europe may be experiencing a productivity slowdown in terms of technical change. Third, technological innovations in the European banking sector are primarily limited to large European banks. McNulty et al. (2022) asserts that small and medium-sized banks in the European region have the most pressing need to update their IT infrastructures.

> "*Our investigations have shown that some banks are still failing to include IT risk in their general risk management frameworks, and that many banks are reliant on outdated systems to perform some of their most critical activities. And, in general, banks have been rather slow to implement our supervisory recommendations in the area of IT and cyber security*".
>
> (European Central Bank, 2018)

In addition, most medium-sized European banks conduct their operations on legacy systems. The presence of monolithic computer applications has severely impacted the front-office businesses of such commercial banks (McNulty et al., 2022). The global financial crisis of 2008 prompted numerous core banking replacement initiatives, and European banks that resisted the trend are currently struggling due to the severe regulatory load, which translates to complicated and costly modifications to IT systems (European Central Bank, 2018).

"In a bank, around 70 percent of the resources are used to just manage regulatory compliance, 20-25 percent spent in maintenance of existing systems and with 5 percent spent on other projects. And even then, this 5 percent are not innovation projects".

(Head of SWIFT, Leading Cooperative Bank, France)[6]

Nevertheless, European banks are gradually investing in technological infrastructure, which focuses on creating a digital ecosystem that enhances the service delivery process, fulfils customer expectations, and improves the competitive positions of banks in the market (Beccalli, 2007; Wang et al., 2021). Results reveal that European banks are continuously improving their technical efficiencies to operate closer to the productivity frontier, and such gains are critical in governing productivity growth. Hence, IT has reduced the technology gap between European commercial banks.

The findings have significant policy implications. It is observed that commercial banks may not be able to sustain IT-driven productivity gains since rivals can readily imitate similar investments. Therefore, IT capital must be supplemented by R&D spending to develop progressive ideas that redefine the competitive landscape of an industry. In addition, the central banks of the BRICS countries should aggressively encourage banks to leverage R&D to broaden the production frontier. In contrast, to decrease waste and promote efficiency, the European Central Bank should prioritize IT investments in European banks with low R&D expenditure. The results demonstrate the success of the 'Lisbon agenda', which sought to make Europe the world's most competitive knowledge-based economy by 2010. The action plan has primarily focused on addressing the stagnated productivity growth in the EU. The vision has emphasized the importance of innovation, research, and development to enhance Europe's competitiveness. Consequently, the policy initiatives have called for increased investment in research and development, the promotion of technology transfer, and the establishment of an environment conducive to innovation and entrepreneurship. Positive productivity payoffs from IT and R&D spending in the banking sector lend credence to the agenda. In addition, the findings support the current policy agenda of "Europe 2020" and the significance of the European Commission's "Innovative Union Initiative". The initiative primarily aims to promote knowledge, innovation, and digital society as drivers of economic development in the EU. It emphasizes the need to invest in research and development, encourage using information and communication technologies (ICT), and improve education and skills to foster a competitive and knowledge-based economy. Positive efficiency payoffs in the banking sector highlight the success of this initiative.

Nevertheless, intra-country comparisons suggest that if IT-driven productivity development is regarded as a nation's long-term goal, industry characteristics should govern the distribution of knowledge capital. The primary purpose of banking regulators has been to improve sectoral efficiency. Therefore, commercial banks must recognise that technology is not a panacea but an instrument for boosting productivity. Its execution involves strategic planning, organizational capabilities, managerial skills, and entrepreneurship.

LIMITATIONS AND SCOPE FOR FUTURE RESEARCH

The present study has some limitations. As advocated by Brynjolfsson and Hitt (1995), any study examining the payoffs from technology is contingent upon the accuracy with which the innovation variables are proxied. The present study employs the aggregate monetary expenditure incurred

[6] Retrieved from the report entitled "Modernising Banks in Europe: Technology Trends and Challenges for Small and Mid-sized Banks" published by IBS intelligence (https://www.temenos.com/wp-content/uploads/2020/11/IBSI-Temenos-WP-Banking-modernisation-in-Europe-v16-Designed-003.pdf).

by commercial banks on technology. Nevertheless, the study does not consider the differences in spending quality among commercial banks. The above limitation primarily stems from the lack of disaggregated bank-level data on the innovation variables of commercial banks. Future extensions of work may include analysing the payoffs from specific investments in technology by employing more granular proxies of IT. Second, constructing a common productivity frontier takes into account intra-regional heterogeneity in banking operations and financial products. Nevertheless, owing to the structural differences in the banking sectors of various countries within the region, there is a possibility that banks of some countries may depict higher (lower) efficiency scores vis-à-vis others. Such heterogeneity may have an impact on the findings. Third, as in the case of any empirical research utilizing secondary data, the findings are subject to measurement errors and are contingent upon the degree of accuracy of reporting. Further, Bloom et al. (2014) contend that technology is an all-pervasive force with far-reaching impacts on the entire organization. Future work can be extended by examining the qualitative impact of technology, primarily focusing on its role in enhancing customer satisfaction, optimizing back-office operations, and improving service quality.

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