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Technological Spillovers and TFP: The Role of Information Communication Technology

[a] Saiqa Lall Hussain, [b] Babar Hussain
[a] PhD Scholar, Visiting Lecturer, International Islamic University, Islamabad, Pakistan
Email: saiqa.lall.vt@iiu.edu.pk
[b] Assistant Professor, International Islamic University, Islamabad, Pakistan
Email: Babar.hussain@iiu.edu.pk

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ABSTRACT
Objective: This research examines the impact of technological spillover on TFP through ICT for developed and emerging countries (OECD & BRICS).
Research Gap: Technology innovated in advanced countries spillover to emerging countries mainly through two classic avenues, including trade (bilateral imports), and foreign direct investment. Technological spillovers can take place through ICT or digitalization. This area has scarcely touched by the researchers. One of the unique features of this channel is that it is least affected by barriers and boundaries.
Design/Methodology/Approach: System GMM technique designed for panel data dynamic set (Arellano & Boverb, 1995; Blundell & Bond, 1998) for 1996-2022. The key benefit regarding this method is that no external instrument is required instead it uses internal instruments to reduce the endogeneity among regressors.
The Main Findings: Our empirical findings support to previous research and theoretical concerns, of ICT positively incentivize growth in nations included in our analyses. Second, while these factors are substitutable and have spillover effects, the conditional impact of ICT is also positive.
Theoretical / Practical Implications of the Findings: International R&D Spillover Theory of (Coe & Helpman, 1993) empirical study based on several recent research on innovation and TFP. Because underlying model of spillover theory extensively studied.
Originality/Value: This study contributes to the literature by offering a multi country econometric analysis of OECD & BRICS, addressing ICT as a carrier of knowledge spillover and positively impact TFP, and recommending policy interventions for sustainable growth.

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Corresponding Author's email address: saiqa.lall.vt@iiu.edu.pk

1. Introduction

Technological Spillovers refer to the knowledge and technology diffusion from one entity to another, resulting in external benefits. These spillovers primarily occur through the trade and foreign direct investment (here after FDI) channels. When a country engages in international trade, it has the opportunity that imported goods and services having foreign advanced technology which is not available domestically and increases total factor productivity (here after TFP). Spillovers aligned with FDI, where multinational corporations bring their technology, management practices, and production methods to the host country. This leads to direct knowledge spillover and technology to the receiving country that increase TFP of the adapting country. Another potential channel of spillovers is information communication technology (here after ICT) and yet has gained less attention of researchers. Present research tries to bridge the gap by analyzing the moderating effect of ICT (viz. the internet usage), in promoting technological spillovers. ICT exposure significantly contributes to spillovers of technology as other countries learn about and imitate technological advancements. Amid rising globalization, grasping the appropriate channel, diffusion of technology between economies is critical for policymakers and firms. Diffusion of technology can limit the benefits for innovation leaders to spend in research and development (here after R&D). So as to preserve the interests of innovators, it is vital to discover how information is shared between countries regarding long-term economic progress. Conversely, if technology transfers from one nation to other, it has substantial policy implications for countries following innovation in terms of world integration. It is widely acknowledged, that international competitiveness of a country is becoming heavily reliant on innovation and technology. Greater trade openness, FDI, and innovations in ICT, will help in providing supportive environment for dynamic R&D activities in a country (Zhu & Jeon, 2007). ICT reshapes international R&D spillovers with suggestions for productivity change in advanced countries with digital setup.

International R&D spillovers diffuse through trade and they are source of productivity growth. Rapid digitalization has changed the knowledge flows across economies. Existing studies treat ICT mainly as a direct productivity factor, leaving unresolved if it complements spillovers (through trade) by enhancing absorption capacity or substitutes for them by enabling autonomous knowledge attainment. This study inspects how ICT conditions the impact of international R&D spillovers on TFP in OECD and BRICS. We have twofold objectives. First, this research is a complement in the field of technological spillovers & TFP offers modern indication of exploring relation of ICT and TFP at macro level, and come with vital insights of ICT as an important channel of knowledge spillover. Second, how ICT conditions the impact of international R&D spillovers on TFP in OECD and BRICS countries.

Our findings shows that when countries benefit from technological spillovers, they improve their TFP, reduce costs, and enhance their competitiveness. This, in turn, facilitate the reallocation of resources across sectors, leading to growth. The present research follows the structure: Section 2 focus on the prior relevant research. Section 3 discuss conceptual framework and statistical modelling. Section 4 comprises data sources, variables construction, and estimation techniques. Section 5 is about results and discussions.

2. Literature Review

2.1 ICT and TFP

The digital economy, mainly driven by the spread of ICTs, offers inspiring opportunities for improving productivity across countries, firms, and regions (Rehman & Nunziante, 2023). Studies show that investing in ICT helps in spreading information and ideas, cuts down transaction costs, saves time, reduce administrative load, ultimately boosts innovation and competition for countries and regions (Czernich et al., 2011). Indeed, ICTs (or digital technologies) are essential in producing goods and services, when used by skilled labor, they improve productivity and economic growth in a country (Myovella et al., 2020). Numerous studies both at micro and macro levels examined the impact of ICT on productivity. At the macro level, digital economy has significant and positive effect on TFP in European regions. Moreover, a 10 % increase in broadband penetration raises GDP by 0.9–1.5 % among OECD countries (Czernich et al., 2011). Over the past twenty years, the ICT has played the leading role in boosting China's economic growth and productivity (Wu & Yu, 2022). International enterprises in America & Europe, found that source structures and ICT might be the key difference in productivity. Similarly, major international businesses can profit by higher ICT investments (Gupta & Kumar, 2018). At the micro level, the adoption of ICT lowers the cost of supplier–customer interactions, increases flexibility and product quality, automates daily tasks, improves business processes, and raises labor productivity (Gal et al., 2019). ICT is a good matched to firms and skilled labor, it can boost firm productivity; however, frequent use of ICT enhances manufacturing firms TFP while also having a crowding-out effect on employment (Acemoglu et al., 2014). ICT can also increase a firm's management ability, inward information flows, & work division (Fort, 2016).

2.2 R&D, ICT and TFP

Digital technologies play a crucial role in globalization by providing a platform that exchange intellectual capital and work anywhere in the world, thereby reducing geographical barriers (Friedman, 2006). In a strict sense, technologies like Big Data, AI (artificial intelligence), robots, and 5G fall under the broader ICT framework, and investment in ICT is a key driver of the digital economy (Rong, 2022).

Technical advancement is a critical driver in boosting TFP, and this progress is deeply rooted in the firms ongoing R&D efforts (Chen et al., 2021). Scholars are usually concerned about how R&D activities intersect with ICT? Investments in ICT and R&D complement one another; generates amplified impacts, pushing firms’ technological advancement. Their interplay can boost a firm's commercial value, although the effect is influenced by features of the industry (Mohnen et al., 2018).

R&D as well as ICT are highly connected to productivity and innovation, where R&D is more important for driving innovation, and ICT is becoming central to productivity. These results suggest that Norway's extensive ICT diffusion may be a crucial factor in explaining the so-called "Norwegian productivity riddle," given the fact that Norway is one of the most productive OECD countries despite low R&D investment (Rybalka, 2015).

At macro level (Sağlam, 2018) examined the dynamic interplay between ICT, R&D, and economic growth by using panel data from 34 OECD nations from 1990 to 2012. Evidence showed bi-directional causality exists between ICT investment and economic growth. Moreover, the findings imply that ICT have a large beneficial effect on human capital formation by boosting the proportion of researchers in overall employment. Within OECD economies, information technology increasingly serves as an important channel for the diffusion of international R&D and productivity growth, gradually becoming as significant as trade and foreign direct investment (Zhu & Jeon, 2007). The development of digital networks and ICT systems speed up cross-border sharing of R&D knowledge and strengthen its effects on productivity (Mohnen, 2001; Zhu & Jeon, 2007).

By facilitating R&D collaboration, ICT contributes to closing technology gaps and improving economic efficiency, through broadband infrastructure and digital connections between advanced and developing economies (Aljneibi et al., 2024).

R&D and ICT jointly account for about 95% of TFP growth within OECD industries; ICT strongly contributes to lowering inefficiency while facilitating knowledge spillovers between industries (Pieri et al., 2018). Technologies related to AI and ICT create notable productivity spillovers with elasticities between 0.01 and 0.06, and exhibit a J-shape curve of Widely applicable technologies (Venturini, 2022). Across EU nations, ICT play an important role in boosting labor productivity, generating substantial international spillover effects. Where a 1% rise in the ICT index corresponds to raise domestic productivity by 0.357% and the productivity of other countries by 0.421% on average (Shahnazi, 2021).

ICT not only cuts inefficiencies but also creates strong spillover effects across industries and countries, extending the gains of input substitution beyond the firm or nation that invests in it. ICT capital acts as a hybrid of conventional and knowledge capital in macro and industry analyses, meaning its use as a substitute for other inputs leads to knowledge spillovers within the country and across borders (Gholami et al., 2009; Pieri et al., 2018; Venturini, 2015) While ICT expansion enhances local socioeconomic development, it can negatively affect nearby areas, illustrating the "digital divide" caused by asymmetric substitution benefits (Wang et al., 2021). Our survey of existing research, discover that there remain certain issues in this domain that require immediate attention. To begin with, there is no consensus on the relationship between TFP and ICT. The outcomes of research in various countries, industries, and time periods are highly variable, and require more precise micro and macro evidence to be supported; so, this study proposes the contribution of ICT to changes in TFP. Another objective of the paper, as much recent work is focused on firm level data from Western industrialized economies, hence this conclusion may not be transferable to other economies (Li et al., 2022).

3. Empirical Modeling

Our Basic model is adopted from (Coe et al., 2009).

$$logTFP = f\ (log\ DR\&D\ capital\ stock, logFRD\ capital\ stock, fraction\ of\ imports\ in\ GDP * log\ FRD) \quad (1)$$

Their estimated model can be written as follows;

$$logTFP_{i,t} = \alpha_i + \beta_1 logDRD_{i,t} + \beta_2 logFRD_{i,t} + \beta_3 \left[m_{i,t}\ log\left(\sum_{j\neq i} \frac{m_{ij,t}}{m_{i,t}}\ FRD_{j,t}\right)\right] + \varepsilon_{i,t} \quad (2)$$

$$logTFP_{i,t} = \alpha_i + \beta_1 logDRD_{i,t} + \beta_2 logFRD_{i,t} + \beta_3 logspillover_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$logTFP_{i,t} = \alpha_i + \beta_1 logDRD_{i,t} + \beta_2 \left(G_7 log\ DRD_{i,t}\right) + \beta_3 logFRD_{i,t} + \beta_4 logspillover_{i,t} + \varepsilon_{i,t} \quad (4)$$

$$logTFP_{i,t} = \alpha_i + \beta_1 logDRD_{i,t} + \beta_2 \left(G_7 log\ DRD_{i,t}\right) + \beta_3 logFRD_{i,t} + \beta_4 logspillover_{i,t} + \beta_5\ hc_{i,t} + \varepsilon_{i,t} \quad (5)$$

Following (Coe et al., 2009; Coe & Helpman, 1995) framework, the empirical model is extended by integrating ICT as another pathway of technological spillovers, leading to a modified equation for TFP expressed as our baseline dynamic model for panel data set for advanced countries:

$$logTFP_{i,t} = \alpha + \beta_0 logTFP_{i,t-1} + \beta_1 logDRD_{i,t} + \beta_2 \left(G_7 log\ DRD_{i,t}\right) + \beta_3 logFRD_{i,t} + \beta_4 logspillover_{i,t} + \beta_5\ Hc_{i,t} + \beta_6 log\ ICT_{i,t} + \theta_i + \mu_t + \varepsilon_{i,t} \quad (6)$$

The variation in TFP is explained by the ICT and spillover. Th model provides a framework to analyze ICT in the evaluation of TFP in developed and emerging economies.

Following is the simplest specification of their equation:

$$TFP = f\,(DRD, G_7 * DRD, FRD, spillover, HC, ICT) \quad \textbf{(7)}$$

Where, TFP is total factor productivity; DRD is a country's own (domestic) research and development capital stock; $G_7 logDRD$ is research and development done by G-7 countries (*Canada, USA, Japan, UK, Germany, Italy, France,*), G_7 variable is a dummy indicator for the seven top research countries by GDP expenditure worldwide in 2021*(in billion U.S. dollars)* on R&D. These countries DRD is substantially exceed as compared to other advanced countries (OECD). We may observe the importance of DRD stocks has a unique impact in larger economies relative to smaller ones by interplaying the dummy of G-7 with DRD stocks; FRD is foreign research and development used by country *I;* $Spillover = m_{i,t}.logFRD$ is import weighted FRD scheme, suggested by (Coe et al., 2009; Coe & Helpman, 1995); HC is human capital; ICT is information communication technology or digitalization (individuals using internet); ICT* log spillover is interaction term of ICT and log of spillover of country *i. i and t are the subscripts for country (i) and time period (t).* α *is intercept,* β_S *refers to regressors,* θ_i *is country specific,* μ_t *is time specific, and* $\varepsilon_{i,t}$ *is error term in all models.*

$$logTFP_{i,t} = \alpha + \beta_0 logTFP_{i,t-1} + \beta_1 logDRD_{i,t} + \beta_2\left(G_7 log\ DRD_{i,t}\right) + \beta_3 logFRD_{i,t} + \beta_4 logSpillover_{i,t} + \beta_5\ Hc_{i,t} + \beta_6\ logICT_{i,t} + \beta_7(logICT_{i,t} * logspillover_{i,t}) + \theta_i + \mu_t + \varepsilon_{i,t} \quad \textbf{(8)}$$

We add interaction term $\beta_7(ICT_{i,t} * spillover_{i,t})$ to capture the impact of spillover on TFP is conditional on ICT. Whether ICT compliment or substitute. We take the partial derivative of above equation with respect to spillover to get conditional effect of ICT.

$$\frac{\partial logTFP}{\partial logSpillover} = \beta_4 + \beta_7 ICT \quad \textbf{(9)}$$

Finally, we explore the channel of ICT. How ICT actually plays a role on TFP. The impact of spillover on TFP declines it weakens if β_7 sign becomes negative then ICT substitutes spillover.

$$logTFP_{i,t} = \alpha + \beta_0 logTFP_{i,t-1} + \beta_1 logDRD_{i,t} + \beta_2\left(G_7 log\ DRD_{i,t}\right) + \beta_3 logFRD_{i,t} + \beta_4 logSpillover_{i,t} + \beta_5\ Hc_{i,t} + \beta_6\ logICT_{i,t} + \beta_7\left(logICT_{i,t} * logspillover_{i,t}\right) + \beta^T\ X_{i,t} + \theta_i + \mu_t + \varepsilon_{i,t} \quad \textbf{(10)}$$

In the end we add $\boldsymbol{\beta^T X_{i,t}}$ vector of control variables (FDI, inflation, population, domestic credit). World trade continues to be a significant mechanism for technological spillovers; ICT emerges as potential pathway for transfer of technology among nations. However, this channel has barely been explored by the previous studies. Present study aims to fill this research question by looking at the relationship between TFP and R&D spillovers for the case of developed countries, but this time through the channel of trade (bilateral import shares) and digitalization (ICT), which has yet to examine in the previous studies. We postulate our hypothesis based on first objective of this study:

$\boldsymbol{H_1}$: *ICT being important channel of spillover and has positive effect on TFP for both advanced and emerging economies.*

4. Data and Methodology

Our unbalanced panel consist of 32 advanced countries, 27 OECD (Australia, Belgium, Austria, Canada, Finland, Denmark, France, Greece, Germany, Iceland, Korea republic, Israel, Mexico, Italy, Japan, Ireland, Netherland, Poland, New Zealand, Norway, Portugal, Sweden, Türkiye, Switzerland, United Kingdom, Spain, and United States). 24 countries are aligned with (Coe et al., 2009; Coe & Helpman, 1995) we added 3 more OECD countries (i.e., Mexico, Polan, Turkey); and 5 BRICS (South Africa, India, China, Russia, Brazil) countries over the period 1996–2022 via annual data. Because they are in top 25 highest GDP ranking 2020-22 of the World Bank1, and among the 20 countries with the largest GDP (in billion U.S. dollars) in 2024 *according to IMF 2* (Liu et al., 2016). Most of the variables at right-hand of equation are expected to be endogenously related to TFP. System GMM technique designed for panel data dynamic sets (Arellano & Boverb, 1995; Blundell & Bond, 1998). The key benefit regarding this method is that no external instrument is required instead it uses internal instruments to reduce

1 https://databankfiles.worldbank.org/public/ddpext_download/GDP.pdf
2 IMF World Economic Outlook Database October 2024. imf.org.@ Statista 2025

the endogeneity among regressors.
Data for variables calculating TFP (GDP constant 2015 US$ as proxy of Y; gross fixed capital formation (constant 2015 US$) as proxy of K; total labor force as proxy of L) is from World Development Indicators (here after WDI) was available for 1996-2022. Bilateral import of machinery & equipment (in thousand US $) from OECD.Stat (BTDIxE Dataset) for country $i's$ from its 31 trading partners for 1996-2021. Trade openness (m) is the share of imports in GDP measured as the Imports of goods and services (% of GDP) from WDI. Human capital (here after HC) based on years of schooling; from Penn World Tables (PWT 11.0) over 1996-2022 as available. Main proxy of ICT such as individuals using the internet (% of population), this proxy is used by many researchers (Adeleye et al., 2023; Aljneibi et al., 2024; Gholami et al., 2009) from WDI for 1996-2022. We use proxy for domestic R&D capital stock (*Total Business expenditure research and development (BERD) in Millions of US$, Constant 2015 prices and PPPs)* from OECD.Stat- MSTI main science and technology database) available for 1995-2020. Brazil and India have no data we take average of 3 countries (China, South Africa, and Russia) of same group.
The domestic R&D stock (here after DRD) in developed country j is calculated through perpetual inventory method and incorporating depreciation (set to five percent) for details see (Coe et al., 2009; Seck, 2012). Following (Coe et al., 2009) the bilateral-import-share weighted foreign R&D capital stock for country i is defined as $S_f^{i-bimw} = \sum_{j\neq i} w_{ij}.S_j^d$. Spillover effect is captured by the cross term of log foreign R&D capital and trade openness (m); $spillover = m.S_f^{i-bimw} or\ logm.FRD$.

Control variables
We have four control variables; all the data is taken from WDI over the period of 1996-2022. Size of a country is measured as total population. The depth of financial systems is measured by the ratio of domestic credit to private sector % of GDP (here after DCPGDP). Macro instability is measured by using proxy of Inflation, GDP deflator (annual %). Foreign direct investment (FDI), net inflow (% of GDP).
TFP: TFP is our dependent variable in all models. We use the classic production function of Cobb-Douglas takes the form as follows: $\boldsymbol{TFP = y/(K^{\beta}.\ L^{1-\beta})}$. Generally, TFP in logarithmic form is expressed as (Zhu & Jeon, 2007).

$$\boldsymbol{logTFP_{i,t} = log\ Y_{i,t} - \beta log\ K_{i,t} - (1-\beta) logL_{i,t}} \quad (11)$$

Where i denotes country$i$, and t is time. Y Represents total output GDP, K shows capital stock, and L is total employment. β denotes the proportion of capital income for country i. We calculated TFP by using above mentioned variables. capital income shares in GDP (β set to 0.35) and 1-β is the average labor share (set to 0.65) for sampled countries (Coe et al., 2009; Krammer, 2014; Seck, 2012). The capital stock is calculated using the perpetual inventory method:

$$\boldsymbol{K_{i,t} = (1-\delta)K_{i,t-1} + GFCF_{i,t}} \quad (12)$$

$$\boldsymbol{K_{i,t} = 0.9K_{i,t-1} + GFCF_{i,t}} \quad (13)$$

δ represents depreciation rate (assumed to be one-tenth=1/10; $1-\delta$= 1-0.1=0.9 when we used delta from PWT the outcome is same as we set it 0.9), $\boldsymbol{K_{i,t-1}}$ capital stock in previous year, and $\boldsymbol{GFCF_{i,t}}$ (Seck, 2012).

5. Results and Discussion
With the final data in hand following section portrays our empirical analysis, the discussion takes place largely in two ways: first, we discuss the descriptive analysis; second, empirical findings.

5.1 Descriptive Analysis
Table 1: Descriptive Statistics

Variables	Observations	Mean	Std. Dev.	Min	Max
GDP constant (US$2015)-Y	864	27.278	1.318	22.981	30.653
Labor Force (L)	864	16.463	1.686	11.947	20.476
Kapital Stock (K)	864	25.673	1.316	21.395	29.169
Total Factor Productivity (TFP)	864	7.605	0.536	5.457	8.378
Domestic R&D stocks (DRD)	832	9.015	1.503	4.063	12.661
Bilateral import Share	832	0.037	0.014	0	0.087
Foreign R&D stocks (FRD)	864	11.301	0.479	9.309	12.835
Imports to GDP ratio (m)	864	34.417	16.382	8.32	124.491
Log Spillover	864	14.738	0.723	11.755	16.831
Human Capital (HC)	864	3.078	0.492	1.64	3.892
Internet (ICT)	861	55.657	31.662	0.013	99.687
FDI net inflow (% of GDP)	832	3.704	7.914	-36.14	86.479

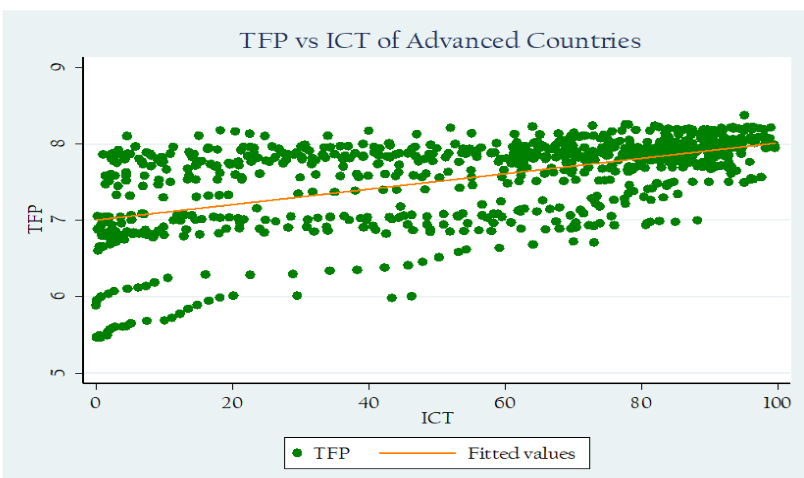
Inflation (% of GDP)	864	3.952	8.421	-5.116	143.64
Log population	832	2.839	0.102	2.526	3.048
Domestic Credit to private sector (% of GDP)-DCPGDP	750	4.386	1.206	-16.441	5.719
Source: Author's own calculations.					

Table 2 presents the correlation matrix of selected countries, among the key variables included in the analysis. As expected, TFP is positively and significantly correlated with several core variables such as foreign R&D stock (0.228), domestic R&D stock (0.159), spillovers (0.412), human capital (0.747), and internet penetration (0.559), indicating that technological advancement, knowledge diffusion, and human capacity are positively associated with productivity levels across countries.

Table 2: Pairwise Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) TFP	1.000									
(2) logDRD	0.16***	1.000								
	(0.000)									
(3) logFRD	0.22***	0.28***	1.000							
	(0.000)	(0.000)								
(4) logSpillover	0.41***	0.04	0.79***	1.000						
	(0.000)	(0.214)	(0.000)							
(5) HC	0.74***	0.46***	0.30***	0.33***	1.000					
	(0.000)	(0.000)	(0.000)	(0.000)						
(6) Internet	0.55***	0.27***	0.61***	0.62***	0.65***	1.000				
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)					
(7) FDI	0.12***	-0.06*	-0.016	0.19***	0.028	0.040	1.000			
	(0.000)	(0.062)	(0.636)	(0.000)	(0.433)	(0.246)				
(8) Inflation	-0.30***	-0.18***	-0.22***	-0.24***	-0.34***	-0.29***	-0.050	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.152)			
(9) DCPGDP	0.41***	0.38***	0.16***	0.056	0.40***	0.43***	0.000	-0.38***	1.000	
	(0.000)	(0.000)	(0.000)	(0.136)	(0.000)	(0.000)	(1.000)	(0.000)		
(10) Popultaion	-0.66***	0.53***	-0.011	-0.39***	-0.33***	-0.33***	-0.14***	0.14***	-0.12***	1.000
	(0.000)	(0.000)	(0.742)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	
Note: *** p<0.01, ** p<0.05, * p<0.1 Author's own calculation										

Figure 1: Scatterplot of ICT & TFP for Sample Countries



Source: Author's own figure obtained from the data set used for estimation.

In contrast, DCPGDP displays positive and moderate association with TFP (0.415), supporting the idea of financial development facilitates capital formation and productivity. Multicollinearity does not appear to be a major concern, although high correlations exist between foreign R&D and spillovers (0.792), this relationship is theoretically consistent. Scatterplot shows that there is positive relationship between internet penetration (ICT) and TFP.

5.2 Empirical Analysis

Table 3 illustrates System GMM estimations corresponding to the models introduced in the preceding section. Following (Coe et al., 2009), the baseline specification is designed to evaluate technological spillovers effects and ICT on TFP. We prefer general to specific model estimations statistically insignificant variables such as inflation and DCPGDP were sequentially excluded from the preferred specification. Next, we discuss the findings of core variables in detail in sequence, starting with the lagged dependent variable displays a consistent magnitude ranging from 0 to 1, has positive sign and highly significant. It shows that the previous year's TFP positively impact the current TFP of advanced countries, indicating convergence and persistence toward equilibrium. A one percent increase in previous year's TFP leads to an increases in current TFP ranging between 0.931 to 0.982 percent, assuming all other factors constant (Bravo-Ortega & García Marín, 2011; Pegkas et al., 2020). There is significant and lasting relationship between TFP and its main drivers, i.e., R&D, HC, and ICT (Borović et al., 2020).

Domestic R&D capital stock *(LogDRD)* exhibits the expected and favorable significant impact on TFP, supports the established theoretical and empirical studies (Coe et al., 2009; Coe & Helpman, 1995; Krammer, 2014; Pegkas et al., 2020; Zhu & Jeon, 2007). A 1 percent increase in DRD enhances TFP by 0.00125–0.006 percent, on average. The effect of G7 countries R&D capital (G7LogDRD), however, is mixed—positive and significant in some specifications [2&3] but insignificant in others—consistent with the observation of limited and context-dependent spillovers from technological leaders, aligns with (Coe *et al*., 2009). Significant and the relatively small coefficients (0.00541–0.00741) suggest that R&D conducted in G7 economies contributes only modestly to productivity improvements in other advanced and emerging economies (Coe & Helpman, 1995; Zhu & Jeon, 2007).

Foreign R&D capital (LogFRD) displays a negative and statistically significant effect (–0.0153 to –0.022 percent), diverging from the predominantly positive effects documented in earlier studies (Coe & Helpman, 1995; Pegkas et al., 2020) .Variation in estimation technique, model specification, sample period, countries included may responsible for this deviation (Seck, 2012). Possible interpretation is that FRD behaves as a *Private Good* which makes it exclusive for the donor country hence rest of the world is unable to benefit from it. No country has direct access to FRD, it is actually, the spillover of FRD that boosts the TFP across the world (Falvey et al., 2002).

The spillover variable, constructed as the import-weighted foreign R&D (logm.FRD), exerts a theoretically consistent, positive and statistically significant effect on TFP, falling between 0.0119% and 0.0243%. This finding indicates that imports serve as the primary channel for transferring embedded technology and in line with "classical Ricardian" model of trade specialization (Coe & Helpman, 1995; Krammer, 2014; Seck, 2012; Zhu & Jeon, 2007). However, current "export-led growth" theory suggests technology diffusion possible through reverse engineering and local firms' decentralization of advanced countries (Krammer, 2014).

Table 3: Spillovers, ICT and TFP Analysis for OECD and BRICS Countries

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Dep var: LogTFP	ICT	ICT*spillover	FDI	Population	Inflation	DCPGDP
L.logTFP	0.931***	0.982***	0.982***	0.968***	0.967***	0.966***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
log DRD	0.00367*	0.00125*	0.00180*	0.00599***	0.00606***	0.00634***
	(0.053)	(0.091)	(0.097)	(0.000)	(0.000)	(0.000)
G7LogDRD	-0.00788	0.00541*	0.00714**	-0.00233	-0.002	-0.0016
	(0.128)	(0.064)	(0.048)	(0.638)	(0.688)	(0.0768)
log FRD	-0.0171***	-0.0187**	-0.0220**	-0.0153*	-0.0157*	-0.0157*
	(0.009)	(0.013)	(0.010)	(0.086)	(0.090)	(0.082)
log Spillover	0.0119**	0.0242***	0.0237***	0.0200*	0.0205*	0.0205**
	(0.014)	(0.006)	(0.008)	(0.051)	(0.051)	(0.047)
Human Capital (HC)	0.0449*	0.0821**	0.0888**	0.0654*	0.0694*	0.0710*
	(0.096)	(0.023)	(0.019)	(0.098)	(0.079)	(0.078)
logICT	0.0581**	0.0913***	0.0575**	0.0598**	0.0605**	0.0613**
	(0.031)	(0.001)	(0.034)	(0.047)	(0.049)	(0.048)
logICT* log Spillover		-0.00519***	-0.00326**	-0.00346**	-0.00350**	-0.00353**

		(0.001)	(0.033)	(0.041)	(0.043)	(0.042)
FDI			-0.00494*	-0.00446*	-0.00453*	-0.00448*
			(0.075)	(0.09)	(0.094)	(0.100)
log Population				-0.133***	-0.136***	-0.143***
				(0.000)	(0.000)	(0.000)
Inflation					3.35e-05	
					(0.808)	
DCPGDP						-0.00108
						(0.243)
Constant	0.0626	-0.0286	0.0105	0.446***	0.454***	0.484***
	(0.450)	(0.651)	(0.883)	(0.001)	(0.001)	(0.002)
Observations	792	793	736	736	736	736
Number of countries	32	32	32	32	32	32
No. of instruments	17	20	24	25	26	26
F test	34464	91417	56443	56343	48047	53717
Prob of F test	(0.000)	0.000	0.000	0.000	0.000	0.000
AR(1)	-2.064	-2.110	-3.049	-3.055	-3.057	-3.056
AR(1) - p value	**(0.0391)**	**(0.0348)**	**(0.0023)**	**(0.00225)**	**(0.00224)**	**(0.00225)**
AR(2)	-1.126	-1.136	-0.702	-0.667	-0.666	-0.664
AR(2) - p value	**(0.260)**	**(0.256)**	**(0.483)**	**(0.505)**	**(0.505)**	**(0.507)**
Sargan	11.14	26.88	31.18	34.20	35.77	35.98
Sargan- p value	(0.266)	(0.00478)	(0.0052)	(0.0019)	(0.001)	(0.001)
Hansen	12.28	13.58	16.51	13.36	13.48	13.15
Hansen - p value	**(0.198)**	**(0.257)**	**(0.283)**	**(0.498)**	**(0.489)**	**(0.514)**

Probabilities are in parentheses *** p<0.01, ** p<0.05, * p<0.1 * symbolize significance at 1%, 5% and 10% respectively.
Notes: L.log TFP is lag of dependent variable TFP. logDRD is log of domestic R&D capital stock; G7logDRD is the dummy variable for G7 countries domestic R&D capital stock; logFRD is log of foreign R&D capital stock; logSpillover is m*logFRD CHH(1997) where m is the share of imports in GDP multiplied with logFRD; hc is human capital; ICT is individuals using the Internet (% of population); ICT*logSpillover is the crossterm of ICT and spillover; FDI is Foreign Direct investment net inflow (% of GDP); LogPopulation is log of total population; inflation is GDP deflator (annual %); DPCPGDP is domestic credit to private sector (% of GDP).

Human Capital (HC) shows positive & significant relationship with TFP across all specifications, ranging from 0.044 to 0.082 consistent with (Awad & Albaity, 2022; Coe et al., 2009). Classical theoretical literature suggest that economic growth is not possible without growth in HC (Lucas, 1988; Romer, 1990). ICT proxied by internet usage -is positive and significant at all levels across all models ranging from 0.058 to 0.091 percent (Adeleye & Eboagu, 2019; Falki, 2023; Myovella et al., 2020). The digital infrastructure and internet usage that exist in country or region have significant impact on the advantage capacity, large economies of scale and reduce costs promotes long term economic growth.

The interaction term (logICT × LogSpillover) shows a negative and statistically significant coefficient (0.00326 to –0.00519), suggesting that ICT moderates, and partially substitutes for, the productivity effects of foreign technological spillovers. Nonetheless, the net effect of spillovers remains positive. For example, in Column 2, the difference between the direct spillover effect (0.024) and the interaction term (0.005) yields a positive total impact of approximately 0.019. This indicates that although ICT dampens the spillover-TFP relationship, it does not eliminate the productivity gains arising from international technology flows (Adeleye & Eboagu, 2019). Furthermore, we examine the conditional effect of ICT on TFP at a low, medium, and high percentiles reported in Table 4 to strengthen above finding.

Conditional Analysis

In order to verify the measured impact of *LogSpillover* on *LogTFP* at different (25th, 50th, 75th) percentiles of *ICT*. The estimated conditional effects represented by β_4 and β_7 have opposite signs, as shown in equation (8).

$$logTFP_{i,t} = \alpha + \beta_0 logTFP_{i,t-1} + \beta_1 logDRD_{i,t} + \beta_2 G_7 logDRD_{i,t} + \beta_3 logFRD_{i,t} + \beta_4 logSpillover_{i,t} + \beta_5 HC_{i,t} + \beta_6 log\ ICT_{i,t} + \beta_7 \left(logICT_{i,t} * logSpillover_{i,t}\right) + \theta_i + \mu_t + \varepsilon_{i,t} \quad (7)$$

$$\frac{\partial logTFP}{\partial logSpillover} = \beta_4 + \beta_7 ICT \quad (8)$$
$$= 0.0237 - 0.00326 * \text{ICT}$$

Table 4: Conditional Effects of ICT on TFP for Advanced Countries

ICT	Coef.	p-values
P_{25} (Low)	0.028**	0.014
P_{50} (Median)	0.011*	0.059
P_{75} (High)	0.009	0.184
Note: *** p<0.01, ** p<0.05, * p<0.1 shows Probabilities (p) at 1, 5, & 10% level of significance. P25, P50, P75 are the 25th ,50th and 75th percentiles.		

Table 4 reports the results of this conditional analysis. The findings show that the effect of technological spillovers on TFP remains positive and statistically significant at the lower (25th) and median (50th) levels of ICT. However, the magnitude of the effect declines as ICT increases, with the coefficient decreasing from 0.028 at the 25th percentile to 0.011 at the 50th percentile, and further to 0.009 at the 75th percentile. While spillovers continue to exert a positive influence, the effect becomes statistically insignificant at the highest level of ICT. This suggests, ICT can enhance domestic innovation capacity, reducing dependency on foreign R&D, but does not completely replace spillover benefits.

From column [3 to 6] we added control variable (FDI, Population, inflation, and DCPGDP) respectively. Four out of two control variables (FDI and population) appear significant. FDI is negative and significant across all models at 10% level of significance. A 1 percent increase in FDI will decrease TFP by (-0.0044 to -0.0049) percent, on average. Inward FDI has a negative and significant impact on TFP. This finding is consistent with (Awad & Albaity, 2022; Ogbeifun & Shobande, 2020; Tsamadias et al., 2019). Even though it is expected to boost, sustained growth in host country is driven by technical spillovers and knowledge transfers. The amount of growth that FDI contributes depends on the degree of complementarity and substitution between FDI and local investment. Also, FDI is more growth-enhancing in technological followers than leaders' countries and sensitive to unobservable country-specific effects.

Second, variable is *Population* which is negative and highly significant in all models consistent with (Inokuma & Sanchez, 2023; Kato, 2016; Lee & Shin, 2021; Peterson, 2017). 1 percent increase in population decrease TFP by (-0.133 to -0.143) percent. Our findings validate that, economic growth declines as population growth increases, as suggested by the Solow growth model. Although traditional growth theory suggests that population growth can spur technological progress and thus TFP. But, empirical evidence in OECD countries shows a negative link between economic growth and population growth (Kato, 2016). In OECD countries, aging population is a major factor reducing TFP growth, which in turn lowers economic growth (Lee & Shin, 2021). There is disagreement on the connection between population growth and economic expansion. While less population in wealthy nations is liable to create economic and social difficulties, excessive population in poor nations can obstruct development (Peterson, 2017).

The diagnostic test results demonstrate that the GMM estimator works properly and produces dependable results. ICT has a substantial impact on spillover in all specifications. According to the findings, expanding ICT infrastructure will significantly promote domestic R&D, economic openness, human capital, and technology spillovers. All of these factors are major drivers of TFP, according to theoretical explanations, and the overall results hold up well across a range of model settings. In particular, the findings align with the research cited in the literature review (Acharya & Keller, 2009; Coe et al., 2009; Coe & Helpman, 1995; Falki, 2023; Krammer, 2014; Pegkas et al., 2020; Zhu & Jeon, 2007).

6. Conclusion

The ICT has reshaped the landscape of global economics, by providing a platform that exchange intellectual capital and work anywhere in the world, thereby reducing geographical barriers. In particular, rapidly evolving ICT have significant effect to productivity & economic activity. Most prior research has looked into the relationship between ICT & TFP, yet unable to reach a conclusion. This study inspects how ICT conditions the impact of international R&D spillovers on TFP in OECD and BRICS.

Findings reveal that ICT consistently enhances productivity, demonstrating its importance as a supplementary asset that enables countries to absorb and utilize technological advancements more effectively. The interaction between ICT and spillovers reveals a nuanced dynamic: ICT moderates the spillover–TFP relationship, with diminishing marginal returns at higher levels of digital penetration. Conditional effects indicate that spillovers significantly enhance TFP at low and moderate ICT levels but lose significance at the highest ICT percentile. This means that, ICT can enhance domestic innovation capacity, reducing dependency on foreign R&D, but does not completely replace spillover benefits.

Overall, the findings emphasize that productivity growth is driven by a combination of domestic innovation efforts, human capital investments, openness to global knowledge flows, and strategic deployment of ICT. Public policies aiming to strengthen R&D capacity, deepen ICT infrastructure, and enhance integration into global technology networks are therefore essential for sustaining long-term productivity and economic growth. As a result, governments should prioritize investment for ICT infrastructure and improving digital skills in lagging regions. These measures would help reduce regional digital disparities and improve TFP, supporting economic and social cohesion across OCED and BRICS.

ICT-Spillover analysis can be done for developing countries for future.

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