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Does Innovation Promote Performance? Evidence from Developed Economies During Crises

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Abstract
This study examines the relationship between firm performance and innovation levels of Information Technology and Communication (ICT), covering 886 firms from five developed countries during the period 2000-2020. The results indicate a positive association between the accessibility and/or the use of ICTs and firms' innovation performance. More precisely, the positive relationship between ICTs and firm performance is highly pronounced in small-sized firms and strongly related to R&D decisions in large firms. However, during the recession period, the relationship between performance and innovation level is affected differently by the financial crisis, leading to contradictory results. Interestingly, the pandemic crisis has had a positive impact on the firm's performance-innovation relationship. Despite high rates of ICT diffusion, the results of performance and innovation cannot be considered universal due to the significant differences between countries. Our findings may contribute to the literature by highlighting how variations in ICT impact firms' innovation performance across countries, particularly during crises.
Keywords: Information and Communication Technology, Performance, Innovation, Financial Crisis, Pandemic Crisis.
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1. Introduction:

In recent times, there has been a widespread belief among scientists, researchers, and managers that firms must embrace digital innovations. These innovations are defined as "the change or creation of products and innovation processes that result from the new combinations of digital and physical components enabled by digital technology" (Liu et al., 2022). It represents; "the driving force for development"; (Schumpeter, 1934) and is increasingly employed as the main concept for governing countries (Wang and Qi, 2021). The significance of information and communication technologies (ICTs) in creating new development avenues, enhancing new driving forces of development, and improving innovation performance has become increasingly the main challenge for firms (Ani and Ofikwu, 2019; Ren-Jye, Hsien, and Keisuke, 2018; Zhou, Gao, and Chimhowu, 2019). Indeed, there has recently been a focus on the rapid development of technology and the increasing use of ICTs. ICTs have fundamentally altered the global landscape, changing economic structures and leading to the development of new types of organizations and social networks (Lechman and Marszk, 2019).

The use of ICTs is critical in achieving innovation since they contribute to all aspects of the innovation process. Numerous studies suggest that ICTs can enhance innovation performance (Shen and Yuan, 2020; Wang and Qi, 2021; Zhu et al.,2021). In the business environment, technology is seen as a vital necessity (Aragón-Sánchez and Sánchez-Marín, 2005; Rivard, 2000), and it is increasingly becoming an integral part of a firm's strategy. The use of ICTs is a key strategy that stimulates innovation and firm performance (Cuevas-Vargas and Parga-Montoya, 2022) and is the primary driving force for development. Therefore, it is essential to consider the impact of a firm's use of technology, particularly when aimed at strengthening innovation activities. ICTs play a crucial role in enabling companies to promote and innovate. According to Guillemette and Paré (2012), the literature is increasingly focused on determining the impact of ICT on firm performance. Similarly, Rousseau et al., (2016) contend that innovation helps firms to enhance performance levels and is a major factor contributing to a firm's growth and economic development, explaining why some firms outperform others. Yeo and Grant (2019) suggest that besides to improving performance, firms can increase sales, market share, and profits through innovation, which can enhance positively their overall performance (De Guimarães et al., 2016; Centobelli, Cerchione, and Singh 2019). Similarly, Vu, Hanafizadeh, and Bohlin (2020) state that causality runs from ICT to economic growth leading to development at the economic as well as the microeconomic levels (Fernández-Portillo, Almodóvar-González, and Hernández-Mogollón, 2020). This is likely to improve firm processes, products, sales, and ultimately increase profits. This predicts that ICTs will play an incremental role in improving the quality of economic development and innovation performance (Ani and Ofikwu, 2019).

From a crisis perspective, the innovation literature highlights that external competitive pressures significantly affect firms' innovative efforts (Klewitz and Hansen, 2014). Currently, two major global crises - the 2007 financial crisis and the COVID-19 pandemic- are in the spotlight for managers and policymakers. The financial crisis led to an extreme environment characterized by high levels of instability, volatility, uncertainty, and ambiguity. This resulted in limited business opportunities, and forced firms to reduce their innovation resources and efforts (Archibugi, Filippetti, and Frenz, 2013; Colombo et al., 2016). On the other hand, The COVID-19 pandemic has caused considerable disturbance across the global economic landscape, creating an environment of uncertainty that is disruptive and challenging for organizations (Biron et al., 2021).

Innovation is a crucial strategy for firms and societies to survive and recover from the pandemic crisis (Wenzel, Stanske, and Lieberman, 2020). Introducing new products, processes, and services that can overcome the challenges posed by the crisis will be crucial to firms' survival and recovery (Roper and Turner, 2020). Additionally, innovation can help firms to maintain their competitiveness during and after the pandemic crisis (Lee and Trimi, 2021; Wang et al., 2020). Therefore, despite the evidence exposed by these studies, there is a lack of consensus about the relationship between crises and firms' performance and innovation. To address this issue, our study investigates the consequences of the financial and pandemic crises on firms' performance and innovative ability in five developed countries from 2000 to 2020. We perform several robustness checks using a cross-country analysis to enhance the credibility of our findings.

Our study makes important contributions to the innovation management literature by examining the relationship between innovation and firm performance during more than one crisis (financial and pandemic crises). Additionally, it adds important evidence that comes in response to the limited studies considering the firm's innovation-performance relationship across all sectors (except the financial sector). Furthermore, only a few previous studies considered the firm's sales proxy measure as a performance measure. Finally, we incorporate three innovation indicators including fixed broadband networks, internet users rates, and the Global Innovation Index (GII).

The present study is structured as follows: section 2 presents the theoretical background and literature review; section 3 describes the methodology, data, and summary statistics; section 4 discusses the main empirical results; section 5 presents robustness checks and additional analyses; and finally, section 6 concludes, highlights relevant limitations, and provides suggestions for future studies.

2. Background Literature: Innovation and Firm Performance:

Innovative resources play a crucial role in driving business growth by creating value and improving inclusive business performance through fostering a culture of innovation and increasing business activities (Chesbrough, 2006; Enkel and Gassmann, 2010). However, the effective and proper use of innovation can be challenging for organizations due to the ever-changing and dynamic nature of the market (Chesbrough, 2006). The availability of skilled experts, diverse assets, and external suppliers also shape the innovative landscape and present further opportunities for organizations to innovate. According to Chesbrough (2003), adopting innovation programs is a key factor for firms' success and is influenced by various factors. Firms can boost sales, market share, and profits through innovation, which promotes their overall performance (De Guimarães et al., 2016; Centobelli, Cerchione, and Singh, 2019). Recent research in the field of operational management emphasizes the importance of innovation in enhancing a firm's performance (Jackson et al., 2016; Lee, Lee, and Garrett, 2019; Lichtenthaler, 2016; Prajogo, 2016).

Innovation is widely acknowledged as a catalyst for knowledge-based economic growth and long-term economic development (Arrow, 1962; Romer, 1990). Nevertheless, innovators may fail to achieve their potential economic benefits due to the uncertainty associated with the innovation process and its market outcomes (Hottenrott and Peters, 2012). To address this issue, scientists attempt to solve these dilemmas theoretically, such as the "Profit from Innovation" framework, which elucidates why innovative companies often struggle to generate substantial economic returns from their innovation ventures (Teece, 1986).

The framework utilized in this analysis of innovation economics encompasses a broader range of factors than previous approaches (Teece, 2018, 2010). Consequently, innovation is recognized as a mechanism that facilitates firms' adaptability and flexibility in response to changing economic conditions (Dougherty and Hardy, 1996) and is closely related to firm performance (Ferreira, Coelho, and Moutinho, 2020; Karlsson and Tavassoli, 2016). Similarly, Siriram (2022) contends that firms operating in a volatile environment may face under-resourcing and limited access to external markets (Zhu et al., 2019). On the one hand, firms with limited resources are often driven to innovate (Bodlaj, Kadic-Maglajlic, and Vida, 2020), and innovation can enable firms to maintain a competitive advantage and a leading role in shaping the future (Lawson and Samson, 2001). Consequently, companies must leverage both internal and external resources and actively engage with connected communities as a prerequisite for innovation, which ultimately leads to improved performance and a competitive edge (Sarasvathy, 2001). To achieve this, businesses must effectively gather and leverage valuable information from their internal and external environments to enhance their performance. In response, the ability to extend

internal knowledge from the external environment is important to complement existing skills (Medase and Abdul-Basit, 2020). Moreover, the capacity to absorb knowledge through networks is a crucial source of innovation that can enhance firm performance and ultimately promote the success of the company (Lawson and Samson, 2001). By this means, firms' innovation abilities need to expand beyond products and support a wider view of innovation (Azar and Ciabuschi, 2017; Bodlaj, Kadic-Maglajlic, and Vida, 2020; Piening and Salge, 2015). However, one of the primary challenges facing innovation research is the need to consider its constituent elements. Information and communication technologies (ICTs) play a critical role in enabling firms to innovate and remain competitive, regardless of the business environment. Thus, technology has become an indispensable requirement for innovation (Aragón-Sánchez and Sánchez-Marín, 2005; Rivard, 2000).

3. Hypothesis Development

3.1. ICT and Firm Performance:

In recent times, the world has witnessed a remarkable technological progress that has led to a shift away from conventional methods of managing firms. Instead, greater emphasis is placed on leveraging information and communication technology (ICT) to reduce operational costs, enhance efficiency, improve communication, and boost firms' performance (Gërguri-Rashiti et al., 2017). Effective management of the technological environment has become a crucial component of a firm's overall strategy (Devaraj and Kohli, 2000). An important question to consider is how information and communication technology (ICT) impacts firms' performance (Lee et al., 2016; Huang et al., 2006; Kossaï and Piget, 2014). For example, Yeo and Grant (2019) suggest that ICT can promote firms' performance. However, Schryen (2013) argues that the impact of ICT on firms' performance is not sufficient and can be better explained by considering the technological infrastructure (Torero and Von Braun, 2006). Neirotti and Pesce (2018) highlight the correlation between ICT expenditure and competitive dynamics in the Italian industry, indicating that firms tend to increase their ICT investment in high-growth industries. This is supported by Roberts et al., (2012) who suggest that munificent industries are likely to have higher ICT expenditure.

On the other hand, the effectiveness of information and communication technology depends on several factors, such as countries' infrastructure (Bankole, Osei-Bryson, and Brown, 2015; Bollou, 2006; Tan, Ng, and Jiang, 2018), manufacturing infrastructure (Archibugi and Coco, 2004) that justifies the investment decision in manufacturing (Vranakis and Chatzoglou, 2012), and/or service technologies to ameliorate significantly the firms' performance (Lee et al., 2016). In this, a study in Uganda argues that ICT implantation improves investment efficiency by 81%, reduces transaction costs by 47%, and enhances performance by 38% (Ssewanyana and Busler, 2007). In addition, it depends on ICT use motives (Zhang et al., 2018). The ICT raises firms' productivity and market share (Cardona, Kretschmer, and Strobel, 2013; Tran et al., 2014), helps firms introduce new products and services, become more customer-oriented, respond better to market changes, and develop their ability to innovate (Hall, Lotti, and Mairesse, 2013; Tran et al., 2014; Gërguri-Rashiti et al., 2017). Thus, Huang et al., (2021) find that ICTs promote firm performance, including financial profitability, marketing performance, and innovation-performance. Regarding the above development, we predict that:

H.1. *The access to and the use of ICT are positively related to the firm's performance. In other words, the global innovation index is positively related to a firm's performance.*

3.2. ICT and Innovation-Performance

The existing literature provides evidence that technology is a crucial driver of innovation and can facilitate the development of new and improved products and services. Effective and efficient use of ICT can promote innovation-performance (Brynjolfsson and Saunders, 2010; Bardhan, Krishnan, and Lin, 2013; Arvanitis, Loukis, and Diamantopoulou, 2013; Shen and Yuan, 2020; Wang and Qi, 2021; Zhu et al., 2021).

Gago and Rubalcaba (2007) argue that technology creates favorable conditions for the development of better products and services. Besides, Ryu and Lee (2018) use service innovation in their research and show that technology plays three roles: an innovation trigger, an innovation enabler, and a true innovator. In the same vein, Nambisan (2013) describes technology as a trigger for innovation that acts on other resources to influence innovation. Carlo et al., (2014) assume that technology plays a reinforcing role rather than a triggering or enabling role.

Shen and Yuan (2020) conducted an extensive panel data analysis of the relationship between ICT and innovation in the China Industry Business. They found a significant positive correlation between ICT use and innovation performance. The authors investigated this relationship across firms of different sizes and efficiency levels. Similarly, Wang and Qi (2021) surveyed 1,550 Chinese firms using World Bank data and found that the use of ICT led to improved innovation performance. In line with these findings, Barbieri et al., (2020) compiled a unique dataset of 480 specialized clusters in Dongguan township, Guangdong Province, and discovered that ICT-specialized firms exhibited better innovation performance. Finally, Zhu et al., (2021) used a sample of 2,700 private and 148 state-owned firms from the World Bank's 2012 survey and found that ICT had a significant

positive effect on both product and process innovation They also noted that the impact of ICT was lower than that of R&D investments.Haut du formulaire Accordingly, we provide the following hypothesis:
H.2*. The access to and the use of ICT has a positive effect on innovation performance. In other words, the global innovation index (GII) has a positive impact on innovation performance.*

3.3. Financial Crisis and Performance

When assessing the impact of the 2008 financial crisis on innovation, researchers have offered mixed or even conflicting evidence regarding corporate investment in R&D. For instance, Paunov (2012) discovered that many companies across eight Latin American countries paused ongoing innovation projects between 2008 and 2009 due to the crisis. Similarly, Archibugi, Filippetti, and Frenz (2013) noted a decrease in European firms' inclination to invest in innovation directly caused by the financial crisis. Nonetheless, some firms deviated from this trend and sustained their R&D investments, and regional variations were observed between northern and southern European countries. Additional studies reported that select European firms either maintained or even increased their investment in innovation after the 2008 shock (Archibugi, 2017). Notably, innovative firms faced more difficulties during the financial crisis than non-innovative firms, mainly due to limited access to external funding.

A study analyzing a sample of 16,000 firms in Germany discovered that innovative firms experienced a similar decline in sales growth as non-innovative firms after 2008. However, innovative firms experienced a more substantial decrease in investment growth than their non-innovative counterparts (Giebel and Kraft, 2019). A comparable situation occurred in the UK, where both innovative and non-innovative firms encountered difficulties in securing financing during the financial crisis. Nonetheless, innovative firms were less successful than others in raising capital and were more likely to face absolute credit rationing (Lee, Sameen, and Cowling, 2015). Similarly, a study conducted by Chung (2017) involving a sample of Korean companies demonstrated a decline in R&D investment following the 2008 crisis, further indicating that external financing for R&D investments became increasingly challenging to obtain for such firms, necessitating the use of internal financial resources. Hence, the next hypothesis was developed:
H.3. *The financial crisis is negatively related to innovative performance.*

3.4. COVID-19 Crisis and Performance

The global lockdown due to the corona-virus disease started in 2019. The COVID-19 pandemic has resulted in an abrupt shutdown of core businesses, a worldwide recession, and a huge crisis for firms (Galanakis et al., 2021). The sudden onset and subsequent accelerated spread of the COVID-19 pandemic have had a devastating impact on numerous businesses. In this, more than 130 firms in the United States have declared bankruptcy since March 2020, citing at least in part the COVID-19 epidemic as the principal factor causing their disappearance. In the wake of significant changes to daily lifestyles and work routines, innovation has become a vital strategy for organizations to survive and recover from the crisis (Zhong et al., 2022). The COVID-19 pandemic has significantly impacted numerous industries, and the inherent uncertainty of the markets has created ongoing challenges and barriers that companies must overcome. However, the crisis is also driving waves of innovation activity (Amankwah-Amoah, 2021). Innovation is crucial for organizations to adapt to rapid changes and remain competitive in the turbulent market environment, especially during the digital age and following the COVID-19 pandemic (Breier et al., 2021; Ebersberger and Kuckertz, 2021; Wang et al., 2020; Wenzel, Stanske, and Lieberman, 2020). As such, improving innovation performance is a key strategic response for organizations operating in a dynamic environment full of challenges and threats, such as the COVID-19 pandemic (Kotabe, Jiang, and Murray, 2017; Zhang, O'Kane, and Chen, 2020). Shin and Kang (2020) investigated the influence of expected interaction and cleanliness on perceived health risks, as well as the intention to reduce customer interaction with employees and enhance cleanliness as a crucial risk-reduction strategy, focusing on technological innovation. In the supply chain area, the COVID-19 pandemic has exposed businesses and companies to gaps in normal trends and their lasting impacts on supply chains. In this, Galanakis et al., (2021) explore potential innovations in the food sector during the COVID-19 crisis, which can be seen as the innovations with the greatest potential in the food supply chain of the new era. Thus, Nandi et al., (2021) provided information on how to make supply chains more resilient, transparent, and sustainable, added to the need to develop location, agility, and digitization features. Lee and Trimi (2021) argue that organizations need to develop a new sustainable core competency, which they call "convergence innovation". This approach is based on the exponential fusion of various objects, technologies, ideas, and strategies, and it can help organizations to stay competitive and to adapt to changing market conditions. In this regard, we provide the following hypothesis:
H.4*. COVID-19 crisis has positive effect on both the firms' performance and innovative abilities.*

3.5. The Firm Size Moderating Role

Firms of various sizes and data management approaches may experience varying levels of government benefits

and demonstrate varying levels of performance. Typically, large firms are considered more visible and socially responsible. In contrast, small firms need to exert less pressure or gain less environmental recognition due to their lower profile. Meznar and Nigh (1995) find that larger firms exhibit lower responsiveness to society and are more resistant to external influences, which is a paradoxical finding. Meanwhile, Symeonidis (1996) notes that there is insufficient evidence to support Schumpeter's (1934) hypothesis that market dominance and large firms stimulate innovation. When certain conditions are met, such as high sunk costs for each task, economies of scale, and the ability to generate innovation rents, a positive relationship between intensity, scale, and innovation activities can emerge. However, academics believe that an organization's ability to invest in R&D depends on the firm's size and level of innovation (Baumann and Kritikos, 2016; Czarnitzki and Hottenrott, 2011; Hall, Lotti, and Mairesse, 2009).

Studies examining the link between firm size and performance yielded mixed results (Dass, 2000; Ruzzier and Ruzzier, 2015), but generally suggest that large firms benefit from economies of scale and are better positioned to engage in global venture capital (Dass, 2000; Ruzzier and Ruzzier, 2015). Bloodgood, Sapienza, and Almeida (1996) find that large firms are more likely to become global market players. So, the relationship between firm size and innovation remains inconclusive (Liu, 2014). Patacconi and Belenzon (2014) suggest that small firms tend to perform better in applied research (patents), while large firms have an advantage in baseline performance research. In addition, Lara et al., (2015) found no significant relationship between the number of patented inventions and SMEs' sales performance. Previous research indicated a positive correlation between firm size and innovation level (Jimenez and Sanz-Valle, 2011). To investigate the impact of firm size on innovation levels in the service sector, Arias-Aranda, Minguela-Rata, and Rodríguez-Duarte (2001) conducted a study on Spanish engineering consulting firms and found that firm size was strongly linked to innovation levels. Furthermore, Audretsch and Acs (1991) observed a significant positive correlation between firm size and innovation levels among German firms.

There is an ongoing debate about whether large- or small-sized firms are more able to capture the potential performance gains of innovation (Damanpour, 2010; Leiblein and Madsen, 2009). In this, Rosenbusch, Brinckmann, and Bausch (2011) advance that innovation is positively associated with the performance in a sample of small- and medium-sized firms, but did not include a comparison with large firms although small firms are, in some cases, seen as more innovative. In this view, we note that high sized firms are generally more able to translate these innovations into performance (Graebner, Eisenhardt, and Roundy, 2010). Hence, the subsequent hypothesis was advanced:

H.5. *The access to and use of ICT are positively associated with performance, especially for large-sized firms. In other words, the relationship between innovation index and innovation performance is stronger for large-sized firms and weaker for small-sized firms.*

4. Methodology

4.1. Sample

To test the validity of our hypotheses, we analyzed the innovation-performance relationship for 886 listed firms across five countries: the USA, Germany, France, Canada, and the UK. These countries are among the world top ten economies in 2022, and are ranked 3rd, 4th, 10th, 11th, and 16th respectively out of 132 economies in the Global Innovation Index. France is the third-largest economic partner of the United Kingdom after the United States and Germany, and these three countries are the most important in Western Europe. The United States is the world's largest economy and Canada is a preferred investment destination. The dataset used in this study contains 16,606 observations extracted from the DataStream database.

Table I. Sample Firm Selection by Country and Industry Sector

Country	Industry Sector	Number of firms	
Canada	Industrials	24	44
	Commercials	10	
	Services	9	
	Technology and Telecommunication	1	
France	Industrials	138	254
	Commercials	26	
	Services	58	
	Technology and Telecommunication	32	
Germany	Industrials	16	25
	Commercials	2	
	Services	3	
	Technology and Telecommunication	4	
United Kingdom	Industrials	107	206
	Commercials	33	
	Services	35	
	Technology and Telecommunication	31	
United States	Industrials	230	357
	Commercials	24	
	Services	14	
	Technology and Telecommunication	89	

4.2. Dependent Variable

We evaluate a firm's financial performance based on its sales and profit volume (S&P), which reflects the actual level of profitability (Chege et al., 2020). Additionally, we incorporate Research and Development (R&D) expenditure as a measure of innovation performance (Usai et al., 2021), calculated by dividing total R&D expenditure by total assets.

4.3. Independent and Control Variables

To analyze the impact of Information and Communication Technology (ICT), we use data from the World Telecommunication/ICT Indicators database (June 2020 Edition). We consider two measures: the number of fixed-broadband subscriptions (FBS) per 100 inhabitants, which includes subscriptions to high-speed internet access via cable modem, DSL, fiber-to-the-home/building, satellite broadband, and terrestrial fixed wireless broadband; and internet users (IU), defined as the proportion of individuals who use the internet from any location. The data were derived from national household surveys. The estimated rate should reflect the total population of the country or, at least, individuals aged 5 years and older. We also incorporate the global index of innovation (GII) to measure a firm's innovation level. To ensure the reliability of the measurements, we reviewed relevant literature on entrepreneurship, innovation, and information systems. We consider two time periods: the crisis period (2007–2009) and the pre- and post-crisis (2000-2007 and 2010-2020) to understand the effects of the financial crisis on firm innovation performance. We include a year dummy variable to account for the financial crisis (with a value of 1 in 2007-2009 and 0 otherwise) and the COVID-19 crisis (with a value of 1 in 2019 and 2020 and 0 otherwise) on innovation performance.

To analyze the impact of country-specific institutional conditions, we include regulatory quality (RQ) and rule of law (RoL) (Marszk and Lechman, 2021) from worldwide governance indicators. We also control for macroeconomic conditions by using GDP growth from World Development Indicators. We control for firm age (Age) as a firm's experience-year since establishment and size (with a dummy variable based on the logarithm of total assets) to account for their effect on performance. To improve the robustness of our analysis, we perform additional tests using subsamples, classifying firms with size values above 15.326 (the median of the Size data is presented in *Table 2*) as large firms and small firms otherwise. Therefore, many studies focus on determining if small firms are better placed to capture the advantages of innovation on firm performance (Leiblein and Madsen, 2009; Rosenbusch, Brinckmann, and Bausch, 2011). We also conduct subsample tests to analyze the heterogeneity of the effects of the pandemic and the financial crisis in different countries.

4.4. Regression Models

We establish the following empirical models to examine the impact of the access to and the use of ICT on firms' performance and innovation performance.

$$FIRM\_PERF_{i,t} = \beta_0 + \beta_1 GII_{i,t} + \beta_2 Fin-crisis_{i,t} + \beta_3 Covid-crisis_{i,t} + \beta_{4-10} Controls_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$FIRM\_PERF_{i,t} = \beta_0 + \beta_1 IU_{i,t} + \beta_2 Fin-crisis_{i,t} + \beta_3 Covid-crisis_{i,t} + \beta_{4-10} Controls_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$FIRM\_PERF_{i,t} = \beta_0 + \beta_1 FBS_{i,t} + \beta_2 Fin-crisis_{i,t} + \beta_3 Covid-crisis_{i,t} + \beta_{4-10} Controls_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$INNOV\_PERF_{i,t} = \beta_0 + \beta_1 GII_{i,t} + \beta_2 Fin-crisis_{i,t} + \beta_3 Covid-crisis_{i,t} + \beta_{4-10} Controls_{i,t} + \varepsilon_{i,t} \quad (4)$$

$$INNOV\_PERF_{i,t} = \beta_0 + \beta_1 IU_{i,t} + \beta_2 Fin-crisis_{i,t} + \beta_3 Covid-crisis_{i,t} + \beta_{4-10} Controls_{i,t} + \varepsilon_{i,t} \quad (5)$$

$$INNOV\_PERF_{i,t} = \beta_0 + \beta_1 FBS_{i,t} + \beta_2 Fin-crisis_{i,t} + \beta_3 Covid-crisis_{i,t} + \beta_{4-10} Controls_{i,t} + \varepsilon_{i,t} \quad (6)$$

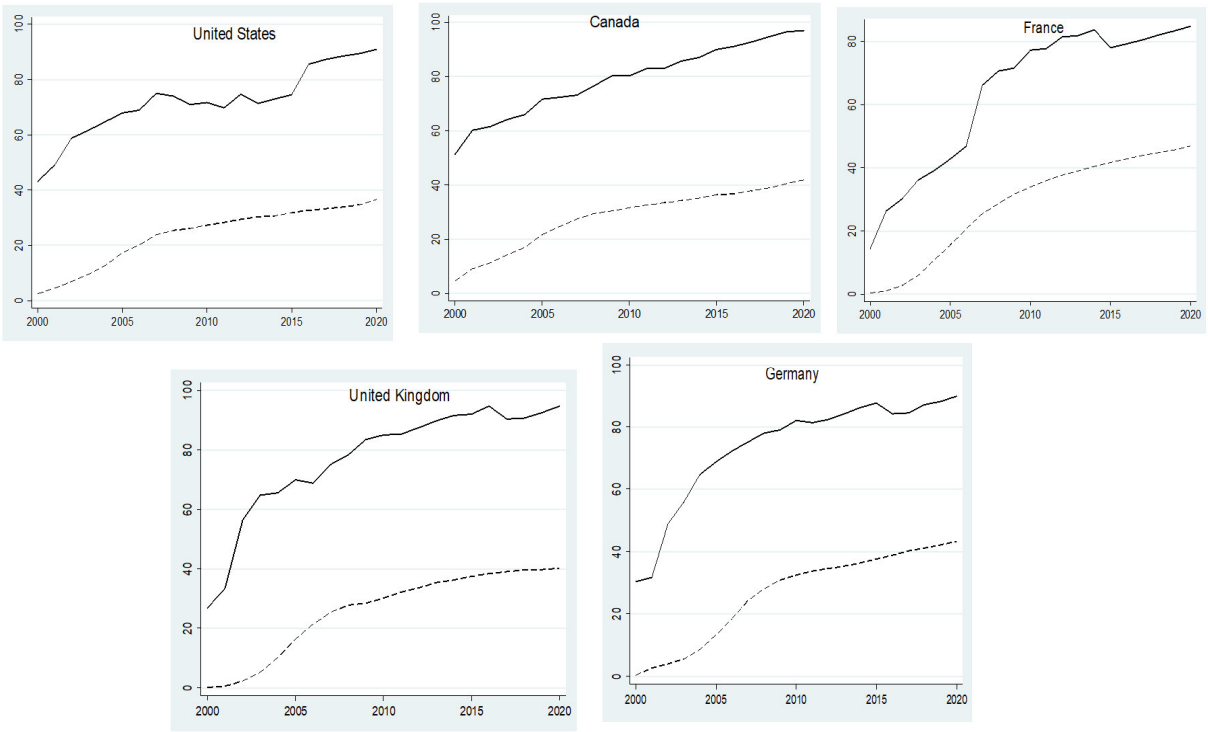
In the above equation, i represents the firm and t represents the year. Our empirical analysis includes variables such as the Global Innovation Index (GII_{it}) as a measure of innovation, Internet users (IU_{it}), and Fixed Broadband Subscriptions (FBS_{it}) in consecutive i-countries and t-years.

Table II. ICT Summary Statistics for the Selected Countries (2000–2020) Annual Data

Country	Obs	Mean	Std. dev	ICT penetration in 2000	ICT penetration in 2020
Internet Users (IU)					
USA	21	71.95	12.16	43.08	90.9
Germany	21	73.40	17.31	30.22	89.81
France	21	63.54	22.35	14.31	84.8
Canada	21	78.98	12.78	51.3	96.97
UK	21	77.03	18.73	26.82	94.82
Fixed Broadband Subscriptions (FBS) [per 100 inhab.]					
USA	21	23.74	10.40	2.51	36.61
Germany	21	26.23	14.35	0.32	43.22
France	21	28.37	15.77	0.33	46.92
Canada	21	28.11	10.74	4.61	41.93
UK	21	25.72	13.84	0.09	40.26

The study's dependent variables are the Sales and Profit (S&P) index for firm performance and Research and Development (R&D) as a measure of innovation performance. We also incorporate the financial crisis ($Fin.crisis_{i,t}$)) and pandemic crisis ($Covid.crisis_{i,t}$) as independent variables, while controlling for other variables such as firm age, country governance indicators (Rule of Law and Regulatory Quality), and GDP growth. The normal error term is represented by ε_{it}. To examine changes in ICT access and use in the selected countries, we use annual time series data on fixed broadband networks and Internet user rates for the period 2000-2020. These indicators measure the progress of ICT proliferation in sample countries presented in Table 2 (and graphically in Figures 1, 2, 3, 4, and 5).

Figure. 1,2,3,4, & 5. ICT diffusion trajectories from 2000 to 2020



Note: we graphically present the distribution of the ICT increases during the same period in each country of our sample in figures 1,2,3,4, and 5 in above. Y-axis: the share of the population with access to ICT; X-axis: time variation; Solid line: Internet Users; & Dashed-line: Fixed Broadband

5. Results

5.1. Summary Statistics

Table 3 presents the summary statistics of the final sample of 18,606 firm-year observations associated with 886 firms using mean, median, standard deviation, maximum, and minimum values. The average level of R&D expenditures for the full sample is $11.77 million, with a large standard deviation of $2.14 million, and a maximum value of $17.57 million. As seen in Table 2, large firms tend to invest more in R&D (mean of 12.75 and median of 12.97) than small firms (mean of 0.42 and median of 10.55). Sales report an average $ 14.70 million for the whole sample (and $16.22 million when excluding small firms), indicating that large firms are more likely to have higher sales compared to small firms. The findings also reveal that the sales and investment in R&D are significantly lower for large firms than for small firms. The average firm's age in the sample is 37.72 years (ln-Age=3.63), with a standard deviation of 1.05 for the period from 2000 to 2020. The countries of our sample hold approximately 70% internet users, with a standard deviation of 0.13. The average fixed broadband subscriptions per 100 inhabitants is 26%, with a standard deviation of 0.13. The maximum value of subscriptions is 46.92, which indicates that the countries of our sample are unlikely to exceed half of fixed subscriptions for high-speed access to the public Internet. The results indicate that sales and R&D investment of large firms are significantly lower compared to small firms.

Table III. Descriptive Statistics

	ample					
Variables	**Observations**	**Mean**	**Median**	**Std. dev**	**Min**	**Max**
R&D	6920	11.77	11.81	2.14	2.48	17.57
S&P	16426	14.70	14.97	2.28	-1.24	20.14
GII	14407	0.33	0.54	0.29	0	.624
FBS	18606	0.26	0.29	0.13	0.09	46.92
IU	18606	0.71	0.74	0.18	14.31	96.97
Age	17870	3.63	3.69	1.05	0	6.22
GDP	18606	0.01	0.02	0.02	-0.09	0.07
Size	16395	15.03	15.33	2.27	0.51	20.5
RQ	17720	1.54	1.51	0.17	1.24	1.89
RoL	17720	1.49	1.56	0.20	1.07	1.88
	e Dummy = 1					
R&D	4024	12.75	12.97	1.87	5.3	17.57
S&P	8338	16.2291	16.24	1.47	-1.24	20.14
GII	4905	0.59	0.60	0.03	.522	0.62
FBS	10408	25.93	29.46	12.62	0.09	46.92
IU	10408	71.86	74.55	17.43	14.31	96.97
Age	9765	3.76	3.93	1.06	0	6.22
GDP	10408	0.015	0.021	0.02	-0.094	0.069
RQ	9935	1.53	1.5	0.174	1.24	1.89
RoL	9935	1.5	1.56	0.18	1.07	1.88
	e Dummy = 0					
R&D	2896	10.42	10.55	1.71	2.48	14.61
S&P	8088	13.13	13.55	1.87	1.38	17.89
GII	3309	0.58	0.60	0.03	.522	0.62
FBS	8198	25.66	28.66	13.96	0.09	46.92
IU	8198	70.16	74.55	18.95	14.31	96.97
Age	8105	3.47	3.43	1.003	0	6.21
GDP	8198	0.014	0.019	0.024	-0.09	0.069
RQ	7785	1.56	1.51	0.168	1.24	1.89
RoL	7785	1.48	1.56	0.225	1.069	1.88

5.2. Correlation Results

Table 4 presents limited high levels of correlation between independent variables, which we intend to use separately in a regression model. Besides, the financial crisis is positively correlated with ICT variables and negatively correlated with the global innovation index (-0.4182). Importantly, both the global innovation index and ICTs infrastructure are significantly positively correlated with sales and R&D investment. Furthermore, there is a strong positive correlation between the levels of innovation measures and the pandemic crisis.

Table IV. Pearson Correlation Matrix

	R&D	GII	FBS	IU	Age	S&P	GDP	RoL	RQ	Fin.crisis	Covid-19
R&D	1.0000										
GII	0.1622 [a]	1.0000									
FBS	0.0973 [a]	0.7918 [a]	1.0000								
IU	0.0501 [a]	0.6931 [a]	0.8747 [a]	1.0000							
Age	0.0318 [a]	0.1049 [a]	0.1208 [a]	0.1566 [a]	1.0000						
S&P	0.5199 [a]	0.0640 [a]	0.0408 [a]	0.1445 [a]	0.3515 [a]	1.0000					
GDP	0.0007	-0.1405 [a]	-0.3390 [a]	-0.2830 [a]	-0.0367 [a]	0.0390 [a]	1.0000				
RoL	-0.1734 [a]	-0.3086 [a]	-0.1938 [a]	0.1674 [a]	0.0798 [a]	0.1993 [a]	0.217 [a]	1.0000			
RQ	-0.3181 [a]	-0.3485 [a]	-0.1946 [a]	0.0875 [a]	-0.0171**	-0.0499 [a]	0.291*	0.516 [a]	1.0000		
Fin.crisis	-0.0256 [b]	-0.4182 [a]	0.0333 [a]	0.0610 [a]	-0.0233 [a]	-0.0066	-0.297 [a]	0.079 [a]	0.0525 [a]	1.0000	
Covid-19	0.0770 [a]	0.3258 [a]	0.3530 [a]	0.3294 [a]	0.0799 [a]	0.0511 [a]	-0.0511 [a]	-0.220 [a]	-0.2635 [a]	-0.1325 [a]	1.0000

[a] and [b] present the level of significance of, respectively, 1% and 5%

5.3. Empirical Results

5.3.1. ICT, GII, and Firm Performance

First, we use the whole sample for the baseline regression analysis using the fixed-effect method. As economic changes occur, researchers and managers have attached more importance to determining the effect of ICT and GII on firm performance.

Table 5 reports the results from Eq. (1,2,3), where the dependent variable is sales revenue (sales). Regarding both GII and ICT penetration among internet users and fixed broadband subscriptions, we find significant positive effects on firm performance at the 1% level in all regressions. This result is consistent with earlier studies on firm performance, such as (De Guimarães et al., 2016; Centobelli, Cerchione, and Singh, 2019), who pointed out that innovation increases sales, market share and profits, eventually leading to an improvement in firm performance. The literature also highlights the importance of policy-makers taking an interest in the use of ICT to enhance firm performance (Gërguri-Rashiti et al., 2017).

Based on Table 5, it is evident that firm age (Age) has a significant and positive impact on firm performance for all models. This contradicts the findings of Ramadani et al., (2019) who suggest that firm age has a negative impact on firm performance in transition economies. The results indicate that the crisis coefficient is negative and significant at the 1% level, implying that firm performance is lower in the crisis period. This may be due to a lack of liquidity, insolvency problems, and government-related issues. The negative correlation between the financial crisis and firm performance suggests that the latter deteriorates during a global crisis (Tan, 2012). Finally, the GII and ICT coefficients remain statistically significant at the 1% level. After controlling for the pandemic crisis, they show weak coefficients (0.130, 0.156, 0.155 respectively) with a positive effect on firm performance. Despite the COVID-19 pandemic, firms have maintained their productivity levels and efficiency with a focus on the significance of healthcare systems, government policy, institutional systems, and good governance (Hu and Zhang, 2021). These results have significant political implications, and policymakers should ensure a favorable environment that emphasizes firm incentives to improve its performance.

Table V. The Determinants of the Firms' Performance (2000–2020)

Models (FE)	S&P	S&P	S&P	S&P	S&P	S&P	S&P	S&P	S&P
GII	0.579***			0.722***			0.562***		
	(0.0289)			(0.0332)			(0.0283)		
FBS		1.952***			1.957***			1.926***	
		(0.0751)			(0.0750)			(0.0747)	
IU			1.255***			1.261***			1.233***
			(0.0571)			(0.0570)			(0.0570)
GDP	-0.697***	1.073***	1.252***	0.564*	0.760***	0.895***	-0.169	1.637***	1.806***
	(0.259)	(0.240)	(0.242)	(0.288)	(0.283)	(0.284)	(0.268)	(0.247)	(0.248)
RoL	0.144*	-0.00207	0.175***	-0.218***	0.0455	0.231***	0.433***	0.217***	0.392***
	(0.0743)	(0.0625)	(0.0639)	(0.0789)	(0.0635)	(0.0649)	(0.0867)	(0.0680)	(0.0693)
RQ	-0.232***	-0.407***	-0.683***	-0.180***	-0.383***	-0.656***	-0.218***	-0.351***	-0.623***
	(0.0494)	(0.0444)	(0.0448)	(0.0490)	(0.0458)	(0.0461)	(0.0497)	(0.0452)	(0.0454)
Age	1.078***	0.754***	0.854***	1.043***	0.745***	0.844***	1.058***	0.735***	0.836***
	(0.0567)	(0.0456)	(0.0445)	(0.0570)	(0.0458)	(0.0448)	(0.0574)	(0.0459)	(0.0447)
Fin.crisis				0.225***	-0.0418***	-0.0482***			
				(0.0200)	(0.0145)	(0.0144)			
Covid-19							0.130***	0.156***	0.155***
							(0.0218)	(0.0221)	(0.0222)
Constant	10.82***	12.01***	11.41***	11.33***	11.94***	11.33***	10.41***	11.65***	11.05***
	(0.239)	(0.198)	(0.193)	(0.250)	(0.197)	(0.192)	(0.231)	(0.196)	(0.190)
R-squared	0.945	0.942	0.941	0.945	0.943	0.941	0.945	0.943	0.942
Observation	12,532	15,609	15,609	12,532	15,609	15,609	12,532	15,609	15,609
Number of ID	880	883	883	880	883	883	880	883	883

Standard errors in parentheses
*, **, ***, present the level of significance of, respectively, 10%, 5%, and 1%.

5.3.2. Firm Size and Firm Performance

The subsample tests in Table 6 verify the positive effects of ICT applications on firm performance. High levels of ICT implementation and GII are associated with improved performance for both high and low-sized firms, especially during the pandemic. We find that the relationship between the financial crisis and firm performance differs in our estimations, as the measurement of innovation is different.

Table VI. The Effect of Firm Size on the Relationship between GII, ICT, and Firm Performance

Models (FE)	S&P	S&P	S&P	S&P	S&P	S&P
				Low Sized Firms		
GII	0.534***			0.662***		
	(0.0344)			(0.0450)		
FBS		1.592***			1.783***	
		(0.0875)			(0.113)	
IU			1.081***			1.049***
			(0.0669)			(0.0837)
GDP	1.568***	1.540***	1.620***	1.485***	2.086***	2.171***
	(0.331)	(0.292)	(0.292)	(0.393)	(0.429)	(0.428)
RoL	0.0700	0.0535	0.205***	0.101	0.416***	0.556***
	(0.0850)	(0.0678)	(0.0699)	(0.121)	(0.0955)	(0.0979)
RQ	-0.0288	-0.0703*	-0.357***	-0.322***	-0.709***	-0.814***
	(0.0427)	(0.0394)	(0.0409)	(0.0858)	(0.0812)	(0.0821)
Age	0.428***	0.301***	0.360***	1.360***	0.866***	0.999***
	(0.0715)	(0.0614)	(0.0612)	(0.0773)	(0.0691)	(0.0656)
Fin.crisis	0.177***	-0.0222	-0.0296*	0.223***	0.0185	0.0163
	(0.0271)	(0.0166)	(0.0164)	(0.0234)	(0.0211)	(0.0211)
Covid-19	0.131***	0.0966***	0.0636***	0.171***	0.198***	0.237***
	(0.0209)	(0.0201)	(0.0199)	(0.0326)	(0.0375)	(0.0375)
Constant	14.25***	14.60***	14.21***	8.580***	10.08***	9.295***
	(0.283)	(0.234)	(0.229)	(0.327)	(0.285)	(0.268)
R-squared	0.937	0.934	0.933	0.928	0.914	0.912
Observation	6,796	8,008	8,008	5,736	7,601	7,601
Number of ID	584	593	593	551	599	599

Standard errors in parentheses
*, **, ***, present the level of significance of, respectively, 10%, 5%, and 1%.

5.3.3. ICT, GII, and Innovation-Performance

To test the effect of GII and the use of ICT on a firm's innovation performance, we used the whole sample for the baseline regression analysis conducted using both fixed and random effect method. The estimated results are presented in *Table 7*. Our results reveal that firms can enhance their innovation performance significantly by utilizing ICTs in their process. The variables show statistically positive coefficients in all estimations, indicating that firms in countries with higher ICT implementation are more likely to invest in R&D, which leads to an improvement in their innovation performance. By examining the coefficients of GII and ICT, we can confirm that access and use of ICT (the use of internet and fixed broadband subscriptions) are more likely associated with innovation performance than GII (global innovation index). Our results align with those of previous studies by Ren-Jye, Hsien, and Keisuke, (2018); Wang and Qi, (2021); Ueki and Tsuji, (2019). In particular, Ueki and Tsuji (2019) find that ICTs infrastructure has a good promoting effect on innovation performance. They underline that ICTs allow organizations to acquire external information in new technology and to share internal knowledge about product, production, market, and consumers.

The results remain robust even after controlling for the crises impact. In fact, the COVID-19 pandemic has shown a positive effect on innovation performance, as demonstrated by the study of Han and Qian (2021), who found that the innovative capabilities of Chinese listed firms increased during the pandemic. We suggest that maintaining strong internal and external knowledge capabilities can help firms to mitigate the effects of the crisis. Firms located in countries with good healthcare systems and good governance are more likely to invest in R&D and acquire external knowledge. However, the financial crisis affects differently innovation performance. It generally has a negative and significant effect. Tan (2012) argues that crises reinforce the negative relationship between financial distress and firm performance, such that highly leveraged firms experience the worst performance during crises.

Table VII. The Determinants of the Firm's Innovation-Performance (2000–2020)

Models	R&D (RE)	R&D (RE)	R&D (RE)	R&D (RE)	R&D (RE)	R&D (RE)	R&D (FE)	R&D (FE)	R&D (FE)
GII	0.726***			0.857***			0.671***		
	(0.0681)			(0.0751)			(0.0347)		
FBS		1.806***			1.805***			1.650***	
		(0.235)			(0.235)			(0.0922)	
IU			1.268***			1.269***			1.132***
			(0.161)			(0.161)			(0.0707)
GDP	-1.732***	1.160***	1.472***	-0.0500	0.530	0.817**	-1.354***	1.443***	1.638***
	(0.420)	(0.300)	(0.303)	(0.410)	(0.358)	(0.351)	(0.417)	(0.391)	(0.395)
RoL	0.176	-0.0113	0.268**	-0.186	0.0792	0.362***	0.488***	0.331***	0.567***
	(0.137)	(0.141)	(0.131)	(0.125)	(0.127)	(0.121)	(0.132)	(0.117)	(0.116)
RQ	-0.243***	-0.590***	-0.900***	-0.209**	-0.557***	-0.866***	-0.170**	-0.490***	-0.774***
	(0.0921)	(0.106)	(0.102)	(0.0913)	(0.107)	(0.102)	(0.0698)	(0.0674)	(0.0663)
Age	0.748***	0.560***	0.608***	0.722***	0.550***	0.597***	0.833***	0.628***	0.688***
	(0.142)	(0.142)	(0.138)	(0.142)	(0.142)	(0.139)	(0.0359)	(0.0359)	(0.0353)
Fin.crisis				0.214***	-0.0676***	-0.0706***			
				(0.0256)	(0.0260)	(0.0258)			
Covid-19							0.117***	0.159***	0.143***
							(0.0357)	(0.0344)	(0.0348)
Constant	8.595***	9.821***	9.223***	9.105***	9.691***	9.087***	7.839***	9.120***	8.552***
	(0.584)	(0.591)	(0.567)	(0.597)	(0.579)	(0.558)	(0.260)	(0.243)	(0.239)
R-squared	-	-	-	-	-	-	0.941	0.932	0.931
Chi2	289.45	246.15	255.22	325.96	248.98	258.39	-	-	-
Prob > chi2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-	-	-
Observation	5,790	6,592	6,592	5,790	6,592	6,592	5,790	6,592	6,592
Number of ID	392	407	407	392	407	407	392	407	407

Standard errors in parentheses
*, **, ***, present the level of significance of, respectively, 10%, 5%, and 1%.

5.3.4. Firm Size and Innovation-Performance

The subsample tests reported in Table 8 confirm the positive effects of the COVID-19 pandemic. Specifically, for small-sized firms, their innovation capabilities increase significantly during the crisis. Faced with the pandemic, firms are more likely to invest in research and development to seek new opportunities to survive and make profits. The crisis represents an opportunity for small firms to innovate in order to respond to new demands. Policy-makers elaborate strategies that support small firms, especially through subsidies, to ensure their continuity. Small firms are more vulnerable and likely to disappear during crises. In columns (2) and (3), the financial crisis primarily affected large firms and may have contributed to the fact that highly leveraged firms have lower performance, as documented by Tan (2012). This, in turn, negatively affects firms' decisions regarding R&D investments.

Table VIII. The Effect of Firm Size on the Relationship between GII, ICT, and Innovation-Performance

Models	R&D (RE)	R&D (RE)	R&D (RE)	R&D (FE)	R&D (FE)	R&D (FE)
	High Sized firms			Low Sized Firms		
GII	0.660***			0.691***		
	(0.0832)			(0.0667)		
FBS		1.612***			1.259***	
		(0.256)			(0.182)	
IU			1.159***			0.797***
			(0.168)			(0.138)
GDP	0.387	0.506	0.689*	0.328	1.206	1.255
	(0.440)	(0.374)	(0.364)	(0.775)	(0.791)	(0.793)
RoL	0.00231	0.0741	0.270	0.238	0.639***	0.821***
	(0.203)	(0.204)	(0.211)	(0.195)	(0.188)	(0.186)
RQ	0.0380	-0.143	-0.459***	-0.172	-0.525***	-0.659***
	(0.0961)	(0.104)	(0.107)	(0.114)	(0.116)	(0.114)
Age	0.171	-0.000150	0.0370	1.233***	1.117***	1.203***
	(0.120)	(0.129)	(0.127)	(0.100)	(0.104)	(0.101)
Fin.crisis	0.166***	-0.0723**	-0.0809**	0.158***	-0.0192	-0.0172
	(0.0374)	(0.0319)	(0.0317)	(0.0402)	(0.0340)	(0.0339)
Covid-19	0.0918*	0.0711	0.0293	0.232***	0.275***	0.288***
	(0.0498)	(0.0590)	(0.0595)	(0.0653)	(0.0727)	(0.0723)
Constant	11.35***	11.97***	11.58***	5.554***	5.786***	5.125***
	(0.552)	(0.567)	(0.575)	(0.450)	(0.481)	(0.456)
R-squared	-	-	-	0.930	0.913	0.912
Chi2	83.65	61.52	68.13	-	-	-
Prob > chi2	0.0000	0.0000	0.0000	-	-	-
Observation	3,390	3,860	3,860	2,400	2,732	2,732
Number of ID	297	304	304	297	304	304

Standard errors in parentheses
*, **, ***, present the level of significance of, respectively, 10%, 5%, and 1%.

5.4. Additional Analysis: Countries Specific Analysis

To strengthen the credibility of our findings, we conducted several robustness checks. Specifically, we conducted a cross-country analysis to examine whether the innovation-performance relationship varies under different country conditions.

Table 9 underlines the strong positive relationship between internet users and innovation performance, which is highly dependent on the proportion of internet users. Canada stands out with the highest proportion of internet users at 96.97%, leading to greater innovation performance. On the other hand, in the French context, internet users are less likely to be associated with innovation performance. Regulatory quality is an important factor contributing to economic activities and firm performance, but its relationship with innovation performance varies across countries. In line with Arvate, Barbosa, and Fuzitani (2013), higher regulatory quality in the USA may lead to lower firm performance and lower investment in research and development. In contrast, Frotagheh and Kardan (2019) find a positive and significant relationship between regulatory quality and innovation performance in the UK. The legal environment also plays a role in business activities. Haggard and Tiede (2011) highlight that the rule of law is strongly associated with institutional development and economic growth, which provide a favorable environment for firms to make business. Our findings in the American context are consistent with previous studies (Gomez, 2016).

However, we find a negative and significant relationship between the rule of law and firm performance in the UK and Germany, according to Frotagheh and Kardan (2019).

Based on our estimation that firm performance deteriorates during a crisis, we can confirm that the global financial crisis had a negative impact on both firm and innovation performance across the entire sample, with the greatest effects observed in the USA and Germany. This result supports the idea that the financial crisis has made

business opportunities less certain, therefore forcing firms to postpone long-term innovation investments (Archibugi, Filippetti, and Frenz, 2013; Colombo et al., 2016; Filippetti and Archibugi, 2011; Paunov, 2012). Moreover, innovation is now considered a crucial strategic response to crises such as the COVID-19 pandemic (Zhong et al., 2022). Our empirical results indicate that innovation performance is positively associated with the pandemic crisis in both the French and British contexts.

Table 10 indicates the relationship between firm performance, innovation performance, and fixed broadband subscriptions. Our findings suggest that the relationship between fixed broadband infrastructure and innovation performance is strong in Canada (β=4.530) and weak in France (β=1.476), despite the fact that France required more infrastructure than the other countries in our sample. The global financial crisis had a negative effect on innovation performance in American, German, and British firms, possibly due to the close relationships between these countries and their partners. Similar to the results presented in *Table 9*, our empirical findings indicate that the pandemic crisis has a similar effect on innovation performance.

6. Conclusion

Using fixed and random effects, this study examines the impact of ICTs proliferation on firms-performance and innovation-performance taking into account the financial and pandemic crisis. Additionally, we classify firms by their stock market indices and conduct a subsample test. Our results demonstrate that high levels of ICT access and use are associated with both firm and innovation performance (measured by R&D) for both small and large companies. Moreover, large firms tend to be strong innovators and invest more in R&D.

However, we also find that the COVID-19 pandemic has significantly increased R&D investment among small companies, and its impact varies across countries. Similarly, the impact of the financial crisis on performance depends on the measurement index of innovation, with large firms being the most vulnerable. Furthermore, our cross-country analysis reveals heterogeneous results. Our findings suggest a significant relationship between regulatory quality, rule of law and innovation performance, which can be direct or inverse depending on the measurement index of ICT implementation. This may be due to changes in governance across countries and governments.

As with any research, this study has certain limitations that could provide directions for future research. Firstly, the geographical scope of the sample is limited to five developed countries, and it would be beneficial to extend it to other regions and countries to conduct a comparative study of innovation behavior between more developed and emergent countries. Another limitation is related to innovation measures, and future research should consider using other innovation indices to measure their effect on firm performance. Additionally, missing data on R&D expenditure limits our analysis, and the ICT variables do not fully capture the range of technologies available to companies, such as data analytics, big data, and artificial intelligence.

Table IX. Firm Performance and Innovation-Performance Versus Internet Users: Country-Specific Analysis (2000-2020)

Country	**USA**		**Germany**		**France**		**Canada**		**UK**	
Perf/Innov-Perf	*Firm-Perf S&P(FE)*	*Innov-Perf R&D(FE)*	*Firm-Perf S&P(RE)*	*Innov-Perf R&D(RE)*	*Firm-Perf S&P(FE)*	*Innov-Perf R&D(RE)*	*Firm-Perf S&P(RE)*	*Innov-Perf R&D(RE)*	*Firm-Perf S&P(RE)*	*Innov-Perf R&D(RE)*
IU	1.920***	1.944***	1.462***	1.205**	0.908***	0.477*	3.746***	4.243***	1.648***	1.730***
	(0.123)	(0.139)	(0.314)	(0.575)	(0.108)	(0.278)	(0.564)	(1.345)	(0.194)	(0.269)
GDP	1.600***	0.483	0.0168	-2.979	2.541***	0.439	0.150	5.545***	-0.0112	-1.289***
	(0.573)	(0.728)	(0.664)	(1.942)	(0.657)	(0.969)	(0.706)	(2.047)	(0.328)	(0.486)
RoL	0.577***	0.687***	-0.598*	-1.810*	0.0727	0.428*	-0.357	0.0964	-0.595***	-0.362
	(0.154)	(0.185)	(0.320)	(0.937)	(0.144)	(0.243)	(0.360)	(1.742)	(0.120)	(0.251)
RQ	-0.529***	-0.556***	-0.0815	0.893	-0.404	-0.531*	0.173	0.137	0.885***	0.902***
	(0.0504)	(0.0614)	(0.173)	(1.061)	(0.299)	(0.316)	(0.253)	(1.827)	(0.160)	(0.268)
Age	1.061***	0.935***	0.0304	-0.267	0.611***	-0.348	0.772***	0.864	0.599***	0.0919
	(0.0869)	(0.101)	(0.166)	(0.321)	(0.0768)	(0.316)	(0.264)	(0.530)	(0.151)	(0.211)
Fin.crisis	-0.0582**	-0.114***	-0.144***	-0.346***	0.00937	0.0823	-0.0395	-0.0958	-0.0433	-0.120**
	(0.0257)	(0.0303)	(0.0556)	(0.0992)	(0.0335)	(0.0619)	(0.0592)	(0.223)	(0.0368)	(0.0540)
Covid-19	-0.00484	0.0176	0.0955	-0.105	0.226***	-0.415	0.0113	-0.389	0.245***	0.246***
	(0.0434)	(0.0550)	(0.0798)	(0.256)	(0.0490)	(0.275)	(0.0688)	(0.337)	(0.0350)	(0.0606)
Constant	10.13***	7.147***	16.38***	14.07***	11.07***	12.52***	9.823***	4.117	9.817***	6.770***
	(0.355)	(0.426)	(0.700)	(1.707)	(0.403)	(1.267)	(1.098)	(5.341)	(0.566)	(0.918)
R-squared	0.894	0.920	-	-	0.943	-	-	-	-	-
Chi2	-	-	49.71	20.73	-	24.95	131.74	59.77	272.94	71.60
Prob > chi2	-	-	0.0000	0.0042	-	0.0008	0.0000	0.0000	0.0000	0.0000
Observation	6,746	3,966	488	448	4,104	692	782	121	3,489	1,365
Number of ID	357	229	25	24	252	51	44	13	205	90

Performance is proxied by sales and profit "S&P" and Research and Development (R&D) as a measure of innovation-performance. ICT is proxied by two types of data from the World Telecommunication/ICT Indicators database (June 2020 Edition): the number of fixed-broadband subscriptions (FBS) per 100 inhabitants: that refers to fixed subscriptions to high-speed access to the public Internet via cable modem, DSL; fiber-to-the-home/building; other fixed (wired)-broadband subscriptions; satellite broadband and terrestrial fixed wireless broadband. Technically, it includes fixed (wired) broadband; satellite broadband, and terrestrial fixed wireless broadband. Besides, we use also Internet users (IU), defined as the "proportion of individuals who used the Internet from any location". The data were derived from national household surveys. The estimated rate should reflect the total population of the country or, at least individuals aged 5 years and older. We also incorporate the global index of innovation (GII) as a measure of a firm's innovation level. Regulatory Quality (RQ) and rule of law (RoL) from Worldwide Governance Indicators to detect the impact of country governance level on innovation-performance. GDP growth from World Development Indicators to control the macroeconomic conditions through countries. The firm age (Age) is a firm's experience-year since establishment. The size is a dummy variable to control the firm size effect (the logarithm of the total asset). We specify a year dummy to take account of the financial crisis that takes the value 1 in the years 2007–2009, and 0 otherwise (2000−2007 and 2010-2020). Also, we incorporate the Covid19 crisis (2019-2020). We specify a year dummy to take account of the Covid-19 crisis that takes the value 1 in the years 2019 and 2020, and 0 otherwise.

Standard errors in parentheses *, **, ***, present the level of significance of, respectively, 10%, 5%, and 1%.

Table X. Firm Performance and Innovation-Performance Versus Fixed Broadband Subscriptions: Country-Specific Analysis (2000-2020)

Country	**USA**		**Germany**		**France**		**Canada**		**UK**	
Perf/Innov-Perf	*Innov-Perf R&D(FE)*	*Firm-Perf S&P(FE)*	*Innov-Perf R&D(RE)*	*Firm-Perf S&P(RE)*	*Innov-Perf R&D(FE)*	*Firm-Perf S&P(RE)*	*Innov-Perf R&D(RE)*	*Firm-Perf S&P(RE)*	*Innov-Perf R&D(RE)*	*Firm-Perf S&P(RE)*
FBS	2.951***	2.885***	1.834***	1.536**	1.476***	0.631	4.530***	5.140***	2.277***	2.430***
	(0.166)	(0.192)	(0.379)	(0.650)	(0.157)	(0.462)	(0.695)	(1.536)	(0.250)	(0.366)
GDP	2.194***	1.048	0.248	-2.796	2.510***	0.0796	-0.327	4.706**	0.897***	-0.203
	(0.579)	(0.735)	(0.676)	(1.939)	(0.647)	(1.100)	(0.702)	(1.856)	(0.302)	(0.467)
RoL	-0.135	0.0158	0.346	-1.033	0.141	0.396	0.281	0.814	-0.458***	-0.255
	(0.156)	(0.190)	(0.324)	(1.014)	(0.142)	(0.248)	(0.339)	(1.741)	(0.111)	(0.239)
RQ	0.110**	0.0659	0.148	1.082	-0.577**	-0.468	0.345	0.189	0.177	0.146
	(0.0508)	(0.0656)	(0.166)	(1.059)	(0.289)	(0.382)	(0.273)	(1.916)	(0.137)	(0.244)
Age	0.984***	0.876***	-0.0389	-0.322	0.560***	-0.335	0.797***	0.902*	0.521***	0.00775
	(0.0879)	(0.101)	(0.161)	(0.318)	(0.0793)	(0.306)	(0.265)	(0.530)	(0.151)	(0.214)
Fin.crisis	-0.00646	-0.0619**	-0.0722	-0.288***	0.0664*	0.102*	-0.143**	-0.201	-0.0420	-0.114**
	(0.0259)	(0.0300)	(0.0509)	(0.101)	(0.0344)	(0.0576)	(0.0641)	(0.208)	(0.0367)	(0.0539)
Covid-19	0.0558	0.0889*	0.0867	-0.117	0.175***	-0.448*	0.0645	-0.322	0.147***	0.135**
	(0.0407)	(0.0522)	(0.0769)	(0.250)	(0.0487)	(0.267)	(0.0708)	(0.369)	(0.0326)	(0.0593)
Constant	11.24***	8.186***	15.56***	13.38***	11.56***	12.54***	10.21***	4.796	11.78***	8.918***
	(0.385)	(0.456)	(0.598)	(1.697)	(0.418)	(1.243)	(1.109)	(5.160)	(0.621)	(0.996)
R-squared	0.896	0.921	-	-	0.943	-	-	-	-	-
Chi2	-	-	51.87	21.03	-	22.14	131.44	53.39	293.39	74.35
Prob > chi2	-	-	0.0000	0.0037	-	0.0024	0.0000	0.0000	0.0000	0.0000
Observation	6,746	3,966	488	448	4,104	692	782	121	3,489	1,365
Number of ID	357	229	25	24	252	51	44	13	205	90

Performance is proxied by sales and profit "S&P" and Research and Development (R&D) as a measure of innovation-performance. ICT is proxied by two types of data from the World Telecommunication/ICT Indicators database (June 2020 Edition): the number of fixed-broadband subscriptions (FBS) per 100 inhabitants: that refers to fixed subscriptions to high-speed access to the public Internet via cable modem, DSL; fiber-to-the-home/building; other fixed (wired)-broadband subscriptions; satellite broadband and terrestrial fixed wireless broadband. Technically, it includes fixed (wired) broadband; satellite broadband, and terrestrial fixed wireless broadband. Besides, we use also Internet users (IU), defined as the "proportion of individuals who used the Internet from any location". The data were derived from national household surveys. The estimated rate should reflect the total population of the country or, at least individuals aged 5 years and older. We also incorporate the global index of innovation (GII) as a measure of a firm's innovation level. Regulatory Quality (RQ) and rule of law (RoL) from Worldwide Governance Indicators to detect the impact of country governance level on innovation-performance. GDP growth from World Development Indicators to control the macroeconomic conditions through countries. The firm age (Age) is a firm's experience-year since establishment. The size is a dummy variable to control the firm size effect (the logarithm of the total asset). We specify a year dummy to take account of the financial crisis that takes the value 1 in the years 2007–2009, and 0 otherwise (2000−2007 and 2010-2020). Also, we incorporate the Covid19 crisis (2019-2020). We specify a year dummy to take account of the Covid-19 crisis that takes the value 1 in the years 2019 and 2020, and 0 otherwise.

Standard errors in parentheses *, **, ***, present the level of significance of, respectively, 10%, 5%, and 1%.

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Declaration of Interest Statement
The authors report there is no conflict of interests to declare.

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