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Digitalization of economy is the key factor behind fourth industrial revolution: How G7 countries are overcoming with the financing issues?

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ABSTRACT

The digitalization role in economy has increased over the years, particularly after the arrival of the industrial revolution 4.0. This paper aims to examine the impact of digitalization in the economy on technological innovation in the presence of business financed R&D expenditures, income, and financial risk for G7 economies for the time period 1990 to 2017. This endeavor uses recently developed econometric approaches, which are superior to traditional first-generation econometric methods. The results show a long-run stable relationship between technological innovation and its determinants (such as digital economy, bank financing R&D expenditure, GDP, and financial risk). Moreover, the digital economy, bank financing R&D expenditures, and financial risk are important factors responsible for technological innovation in G7 countries. This study has meaningful policy implications for decision-makers in designing their policies related to the digital economy, bank financing, and technological innovation in G7 countries. The cost of innovation is significantly high, for which bank finance is sufficiently required. However, due to the high financial risk firms, banks often reluctant to finance innovative ideas. Hence, for nurturing technology through digitalization in economy and business financed R&D expenditure, financial risk must be minimized.

1. Introduction

The digitalization in economy plays a vital role in the economic growth of a country, and technological innovation is not achievable without digitalization and plays a significant role in affecting factor productivity. The amazing performance of G7 countries in achieving high economic growth is due to an improved degree of technological innovation and other factors. In recent years, the digitalization of economies in the form of advancement in Information and Communication Technologies (ICTs) have changed the business dynamics of G7 countries. These digitalization advancements have improved G7 economies in terms of increased productivity, social change, and industrial development. These great seven countries represent 58% of the global net wealth (OECD, 2019). Moreover, the economic performance of G7 countries are significantly improving over the years. Besides, these great seven economies are spending billions of dollars on research and development (R&D), which has boosted their economic and innovation performance. Therefore, as far as the G7 countries are concerned, it is necessary to analyze the impact of digitalization and R&D on technological innovation. Thus, the G7 countries account for a large share of the world's net wealth, their technological innovation has increased, and they have also made progress in digitalization. The literature on the determinants of technological innovation is rich. Income, imports, human capital, institutional quality, financial development, debt financing, corruption, knowledge spillovers, and most importantly, R&D investment are considered important determinants of technological innovation.

However, the digital economy, as a determinant of technological

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innovation, has never been analyzed. The research on the link between the digital economy and technological innovation is scarce. By introducing digitization as a new explanatory variable, this research fills the gap in the literature. The roots of digitalization in economy date back to around the 1990s with the emergence of the internet, which transformed the economic and industrial structure (Schwab, 2017). Digitalization in economy has increased over the years, particularly after the arrival of the fourth industrial revolution. The automation of economy and artificial intelligence refers to digital technologies, have transformed the economic and business structure and performance (Su et al., 2020b; Umar et al., 2020). The concept of digitalization in economy covers progressive digital technologies, which help to surge the efficiency of social production (Pradhan et al., 2019). The digital economy is based on ideas, knowledge, creativity, and innovation (Johnson, 2019). Countries around the globe are transforming their economies through digitalization. However, digital technology development has a significant lag and the time taken to introduce it into markets (Galichkina, 2014). Moreover, there is a significant coordination lag between countries in the development of digital technologies. In the modern era, the world output has increased by manifold due to technological changes in businesses and institutions. The advancement in Information and Communication Technologies (ICTs), the internet of things, and digital format have changed the business dynamics. Besides, institutional quality and organizational structure have largely been changed due to these advancements. The advancement in digitalization in economy has improved national economies in terms of an increase in productivity, social change, and industrial development. Due to these reasons, the phenomenon of digitalization in economy also refers to the new industrial revolution (Lee et al., 2018).

In recent years, countries worldwide have transformed their economies through liberalization reforms to boost their economic performance, which has increased the competition among firms (Law et al., 2018). As a result, firms have increased their spending on research and development (R&D) expenditures. These developments have large implications for the strengthening of domestic economies as domestic goods are now more modernized, attracting domestic buyers. Hence, the demand for imports has decreased in countries with an increased degree of innovation, high R&D expenditures. Business-financed R&D expenditure is considered an important factor in explaining industrial competitiveness and specialization (Su et al., 2020a). These expenditures are vital for creating new products and hence, improve the process of innovation. Moreover, these R&D expenditures significantly impact the cost competitiveness of the economy (Curtis et al., 2020). By focusing on R&D expenditures and consistent policies, G7 countries have transformed their economies from imitating countries to a group of innovative economies. Hence, along with digitalization in economy. Falvey et al. (2006) note the protection of ideas and creativity as another important determinant of encouraging innovation. However, for nurturing technology through digitalization in economy and business financed R&D expenditure, financial risk must be minimized.

Since the cost of innovation is significantly high for which bank finance is sufficiently required, nevertheless, due to the high financial risk of firms, banks often reluctant to finance innovative ideas. Hence, high financial risk is considered as an impediment in the way of technological innovation. To sum up, digitalization in economy and R&D expenditures have great implications for technological innovation. However, to reap the positive benefits of these factors, financial risk must be minimized. Hence, it is imperative to analyze the linkages between digitalization in economy, R&D expenditures, and financial risk with technological innovation. This study's main objective is to investigate the impact of digitalization in economy on technological innovation in the presence of business financed R&D expenditures, income, and financial risk for G7 countries over the period of 1990 to 2017. The main reason for selecting G7 countries is, these great seven countries represent 58% of the global net wealth (OECD, 2019). Moreover, the economic performance of G7 countries are significantly improving over the years. The amazing performance of G7 countries in achieving high economic growth is due to an improved degree of technological innovation and other factors. In recent years, The digitalization of economies in the form of advancement in Information and Communication Technologies (ICTs) have changed the business dynamics of G7 countries. These digitalization advancements have improved G7 economies in terms of increased productivity, social change, and industrial development. Moreover, these great seven economies are spending billions of dollars on research and development (R&D), which has boosted their economic and innovation performance. Therefore, we analyze the effect of digitalization and R&D on technological innovation in the case of G7 countries. To serve this purpose, we constructed the digital economy Index by using Principal component analysis (PCA) by considering the accessibility of households and industry to the internet and mobile. To answer whether digitalization in economy has related to technological innovation, this study uses recently developed econometric approaches, which are superior to traditional first-generation econometric methods.

The paper is organized as follows: Section 2 provides the literature review, and the theoretical framework related to determinants of financial development is provided in Section 3. This section also presents the methodology used in this paper. Section 4 provides the results and discussions. Section 5 presents the concluding remarks and policy implications.

2. Literature review

The quest for finding potential determinants of technological innovation has been a popular topic for researchers and academia. The literature in this regard has developed in two somewhat different aspects: theoretical models and empirical analyses. Moreover, the literature can also be grouped into two different types of studies: micro and macro-level innovation determinants. The revolutionary work of Schumpeter (1950) provided a base for further decisions on the company's decisive innovation. Researchers such as (Aghion et al., 2005; Balasubramanian and Lee, 2008; Grossman and Helpman, 1991; Souitaris, 2002; Wolfe, 1994) have identified stock of knowledge, decision making, industrial sector, business strategy, information processing structure, R&D spending, infrastructure, country environment and firms' access to financial resources as the factors that affect responsible for firm's rate of innovation. At a macro level, the quest for finding the factors responsible for innovation at the country level has emerged as one of the policy-makers and researchers' major concerns. In the literature, income, imports, human capital, institutional quality, financial development, debt financing, corruption, knowledge spillovers, and R&D investment are considered as important determinants of technological innovation (Berg et al., 2019; Burhan et al., 2017; Danquah and Amankwah-Amoah, 2017; Dincer, 2019; Xin et al., 2019).

Barro and Lee (1996) argued that the income of the country is vital for innovation. The factors such as infrastructure and R&D spending depend are much determined by income. Henceforth, an increase in the income of the country improves the technological innovation of the country. According to (1996), variation in government policies, as echoed in infrastructure, institutional quality, tax system, and property rights maintenance degree, are responsible for differences in countries' technological level. Harley (2003) also supports Barro by arguing that the main reason behind the continuous economic growth is the persistence of technological change. Falvey et al. (2006) consider ideas creativity as important factors responsible for innovation. The literature on the role of digitalization in economy in affecting economic growth and technological innovation is scant. Only a few empirical studies are carried out to examine different aspects of the digital economy (Afonasova et al., 2019; Galichkina, 2014; Johnson, 2019; Park and Choi, 2019). Studies have been conducted in the empirical literature to compare the countries by analyzing the digital economy's different components. The digital economy components include the Global Innovation Index (GII), Networked Readiness Index, Internet

accessibility, ICT Development Index, and High-Technology Exports (Richter et al., 2017).

Researchers such as Afonasova et al. (2019) compared Russia and EU countries' economies by analyzing the components of these countries' digital economy. Moreover, the authors compared Russia and EU countries' economies in terms of the depth of these countries' digital economy. By analyzing the effect of different digital economy components on economic growth and social processes, the authors find that Russia has a strong position in the digital economy's two components: Network Readiness and ICT development. However, the country is far behind than EU countries in the production of High-Technology Exports, which require high R&D expenditures. Ahmad and Schreyer (2016) studied the digital economy's statistical challenges, such as measurement problems. The authors highlighted some of the important measurement challenges, such as the accounting framework for GDP. Several measurement issues affect the strength of the digital economy, e.g., measurement of international transactions. (Yoo et al., 2010) contributed to the literature by analyzing the implications of persistent digitalization on innovations. The author argues that an emergence of new layered product architecture is possible due to the digitalization of products. Hence, the digitalization of the product and economy is essential for achieving technological innovation. On the role of bank financing R&D expenditures in affecting technological innovation, the literature is rich (Aghion et al., 1998; Conte and Vivarelli, 2014; Curtis et al., 2020; Hoppmann et al., 2013; Su et al., 2020a). Moreover, bank financing R&D expenditures are positively related to innovation. The theoretical rationale for the positive link between BFR&DE and technological innovation is that since business financed R&D expenditure is considered an important factor in explaining industrial competitiveness and specialization, these expenditures are vital for creating new products and hence, improve the process of innovation. Moreover, these R&D expenditures significantly impact the cost competitiveness of the economy (Curtis et al., 2020). Firms that are able to finance their R&D investment through internal funds or external finance, such as banks or other financial institutions, get continuous technological improvements through innovation. Hence, financing of R&D through banks is vital for innovation. However, financial risk is an impediment in the way of technological advancement. The theoretical rationale for the link between financial risk and technological innovation is that banks often reluctant to finance innovative ideas due to the high financial risk of firms. Hence, high financial risk is considered as an impediment in the way of technological innovation. High financial risk leads to low expected returns (Isik and Hassan, 2003), which in turn reduce the bank financing of R&D expenditures. According to Ali et al. (2011), all financial institutions face financial risks such as market risk, operational risk, liquidity risk, interest rate risk, credit risk, foreign exchange risk, and other business risks. These risks negatively affect the bank financing of R&D investment.

This paper aims to examine the impact of digitalization in economy on technological innovation in the presence of business financed R&D expenditures, income, and financial risk for G7 countries over the period of 1990 to 2017. This study contributes to the existing literature by examining a new set of potential determinants of innovation. In the existing literature, income, imports, human capital, institutional quality, financial development, debt financing, corruption, knowledge spillovers, and most importantly, R&D investment are considered as important determinants of technological innovation. However, the digital economy, as a determinant of technological innovation, has never been analyzed. Moreover, this study uses bank financing R&D expenditure as a new determinant of technological innovation. Previous studies have used R&D expenditure as responsible for technological innovation. We differentiate between total R&D expenditures and bank finance R&D expenditures. This study uses recently developed econometric approaches, which are superior to traditional first-generation econometric methods. Criticism of previous research is based on using traditional econometric methods to analyze the factors responsible for innovation. Therefore, this research adds to the literature in a meaningful way.

3. Data, model specification, and methodology

3.1. Data

Our main objective in this study is to analyze the digitalization in economy on technological innovation in the presence of business financed R&D expenditures, income, and financial risk for G7 countries over the period of 1990 to 2017. According to previous literature, we use many factors that play a decisive role in technological innovation. Specifically, in the model, we use the following variables: gross domestic product measured at constant 2010 USD (GDP), Patents both resident and non-resident (TI), business financed research and development expenditures (BR&D), digital economy measure as households with internet access (%), Industry internet access, Households with Mobile broadband Internet access (%) (DE), and financial risk index is measured different value ranges from 0 to 50 (FRI). FRI shows 0 with high risk and 50 as very low-risk. The data of GDP and TI comes from World Bank (WDI, 2019),[1] BR&D and DE data is obtained from Organization for Economic Cooperation and Development (OECD),[2] and FRI gathered from Political Risk Services (PRS).[3]

3.2. Model specification

This study empirically examines the linkages between technological innovation with its determinants, including the digital economy, bank financing R&D expenditures, income, and financial risk in the case of G7 countries. The basic model specification for this study is given as:

$$TI_{i,t} = \lambda_1 DE_{i,t} + \lambda_2 BR\&D_{i,t} + \lambda_3 GDP_{i,t} + \lambda_4 FRI_{i,t} + \varepsilon_{i,t} \quad (1)$$

Where, TI is technological innovation measured through the number of patents for non-residents and residents, BR&D is business financed research and development expenditures, DE is digital economy Index constructed by using Principal component analysis (PCA). This index is constructed based on (Households with Internet access (%), Industry internet access, Households with Mobile broadband Internet access (%)) and FRI is a financial risk index.

Following Afonasova et al. (2019), we expect a positive impact of the digital economy on technological innovation. The theoretical rationale for the link between the digital economy and technological innovation is that digitization has changed the business dynamics, institutional quality, and organizational structure. All these structural and institutional changes have implications for technological innovation. Hence, it is perceived that the digital economy is positively related to innovation, i.e., $\lambda_1 = \frac{\partial TI}{\partial DE} > 0$. To improve technological innovation through digital economy, firms and countries need heavy investment in R&D. To finance these R&D expenditures and cost innovative projects, and firms need financing. The bank plays an important role in financing R&D expenditures. Following Aghion et al. (1998), Hoppmann et al. (2013), Conte and Vivarelli (2014), and Curtis et al. (2020), we introduce bank financing R&D expenditure as a determinant of technological innovation. Business financing R&D expenditure is considered an important factor in explaining industrial competitiveness and specialization. These expenditures are vital for creating new products, which improve the process of innovation. Hence, it is perceived that the variable bank financing R&D expenditures is positively related to innovation, i.e., $\lambda_1 = \frac{\partial TI}{\partial BFR\&DE} > 0$. This study includes GDP as an explanatory variable in model 1, to gage the impact of income on technological innovation. The

[1] https://databank.worldbank.org/
[2] https://stats.oecd.org/#
[3] https://www.prsgroup.com/

income of the country is a necessary condition for technological innovation. Barro and Lee (1996), in his study, he argues that the income of the country is vital for innovation. Factors such as infrastructure and R&D spending depend on national income. Hence, an increase in the income of the country improves the technological innovation of the country, i.e., $\lambda_3 = \frac{\partial TI}{\partial GDP} > 0$. Following Isik and Hassan (2003) and Ali et al. (2011), this study includes financial risk as an explanatory variable in the empirical model. High financial risk is considered as an impediment in the way of technological innovation. High financial risk leads to low expected returns, which in turn reduces the bank financing of R&D expenditures. Hence, we expect a negative impact of FRI on TI, i.e., $\lambda_4 = \frac{\partial TI}{\partial FRI} > 0$.

3.3. Methodology

There are six steps in the estimation procedure. First, this study employs the cross-sectional dependence (CD) test introduced by (Pesaran, 2004). CSD is an indispensable issue in panel data econometrics and can cause severe problems such as dimensional distortion and unit root test error. This study uses the Lagrange multiplier (LM) test, scaled LM test, bias-corrected scaled LM test, and CD test developed by Breusch and Pagan (1980), Baltagi et al, (2012), Pesaran et al. (2008), and Pesaran (2004), respectively. Second, to test the slope homogeneity, this study utilizes the test homogeneity test popularized by (Pesaran and Yamagata, 2008). The ability to measure panel-specific heterogeneity is vital in analyzing panel data (Hao et al., 2021; Ji et al., 2020). When the panel is heterogeneous, a slope homogeneity supposition will result in misleading outcomes (Ahmad et al., 2020; Gu et al., 2020; Li et al., 2021).

Third, for stationary analysis, this study further uses the cross-sectional augmented Im, Pesaran, and Shin (CIPS) test introduced by Pesaran (2007). The test deals with CSD and slope heterogeneity. However, for a robustness check, we employ several other first-generation tests. The general equation for CIPS (2007) is given below:

$$\Delta Y_{i,t} = \varphi_i + \varphi_i X_{i,t-1} + \varphi_i \overline{Y}_{t-1} + \sum_{l=0}^{p} \varphi_{il} \Delta \overline{Y_{t-l}} + \sum_{l=1}^{p} \varphi_{il} \Delta Y_{i,t-l} + \tau_{it} \quad (2)$$

Where and shows cross-section averages. Similarly, the CIPS equation is provided as:

$$\widehat{CIPS} = \frac{1}{N} \sum_{i=1}^{n} CADF_i \quad (3)$$

In Eq. (3), CADF refers to a cross-sectional augmented dickey fuller.

Fourth, this study uses the (Westerlund, 2007) cointegration test, which has the power to deal with both CSD and slope heterogeneity. The test is constructed by using four test statistics such as G_t, G_α, P_T and P_α.

Where, $G_t = \frac{1}{N}\sum_{i-1}^{N} \frac{\alpha_i'}{SE(\alpha_i)}$, $G_\alpha = \frac{1}{N}\sum_{i-1}^{N} \frac{T\alpha_i}{\alpha_i'(1)}$ are for group statistics and $P_T = \frac{\alpha'}{SE(\alpha)}$ and $P_\alpha = T\alpha'$ are for panel statistics.

Fifth, to estimate the long-run coefficients, this study uses the augmented mean group (AMG) method developed by Eberhardt (2012). AMG method is robust as compared to other methods. The AMG equation is provided as:

$$\Delta Y_{i,t} = \theta_{1,i} + \theta_{2,i} \Delta EV_{i,t} + \theta_{3,i} UCF_i + \sum_{t=2}^{T} \theta_{4,i} TD_t + \varepsilon_{i,t} \quad (4)$$

In the equation, the dependent variable is denoted by $Y_{i,t}$, $EV_{i,t}$ is for all explanatory variables, Unobservable common factors represent by $UCF_{i,t}$ and TD is a time dummy.

Lastly, the Common Correlated Effects Mean Group (CCEMG) estimators (Pesaran, 2006) were implemented for long-run evaluations. The robustness check was done by the Fully Modified Least Square (FMOLS) method (Pedroni, 2001).

4. Results and discussions

The cross-sectional dependency results demonstrate that there are ample shreds of evidence that all variables are cross-sectionally dependent. A shock in a variable in one of the G7 countries has implications for other G7 countries. The cross-sectional dependency is evident from all four tests (such as BP-LM, PS-LM, BCS-LM, and P-CD). The lower part of Table 1 provides the results of the slope heterogeneity test. The significant values of Delta-tilde (DT) and Adjusted delta-tilde (ADT) confirm the existence of slope heterogeneity in the model.

Table 2 provides the results of panel unit root tests. We employ first and second generations unit root tests. However, we rely on the second-generation CIPS unit root test results because it considers the panel data problems (mentioned in Table 1). The CIPS test results show that all variables are stationary at the first difference, i.e., I(1).

Table 3 provides the results of the panel cointegration test. We employ the Westerlund cointegration test. The results show that technological innovation is cointegrated with its determinants, such as the digital economy, bank financing R&D expenditures, GDP, and financial risk. Group and panel statistics' significant values support our claim about the long-run relationship among variables in model 1.

To empirically analyze the impact of the digital economy, bank financing R&D expenditures, GDP, and financial risk on technological innovation, this study used CMG and AMG econometric methods. The results suggest that GDP, digital economy, bank financing R&D expenditures, and financial risk are important factors responsible for technological innovation in G7 countries. Except for the financial risk index, all other variables are positively related to technological innovation. We inferred some interesting results: First, bank financing R&D expenditures (BR&D) are positively related to technological innovation. By focusing on R&D expenditures and consistent policies, G7 countries have transformed their economies from imitating countries to a group of innovative economies. Business financing R&D expenditure is considered an important factor in explaining industrial competitiveness and specialization. These expenditures are vital for creating new products, which improve the process of innovation. These results are similar to the findings of (Conte and Vivarelli, 2014; Curtis et al., 2020; Hoppmann et al., 2013). Second, the variable digital economy positively affects innovation, supporting the earlier findings (Afonasova et al., 2019). The digital economy in the form of automation of economy and artificial intelligence has transformed the economic and business structure and performance. The positive impact of digitalization on technological innovation has great implications for G7 countries. G7 countries are transforming their economies through digitalization. Digitalization in economy has changed the business dynamics, institutional quality, and organizational structure of these countries. All these structural and institutional changes have implications for technological innovation.

Third, the variable GDP positively affects innovation, which supports

Table 1
Cross-sectional dependency and slope heterogeneity tests.

Variables	BP-LM	PS-LM	BCS-LM	P-CD
DE	468.69***	69.08***	68.95***	21.53***
FRI	106.53***	13.19***	13.06***	4.70***
GDP	528.07***	78.24***	78.11***	22.93***
TI	159.64***	21.39***	21.26***	6.23***
BR&D	419.45***	61.48***	61.35***	20.26***
Heterogeneous/Homogeneous slope Coefficient Test				
Delta-tilde (DT)		Adjusted delta-tilde (ADT)		
8.681****		8.028*p**		

Note: ***, **, * is for 1%, 5% and 10% statistical significance level. BP-LM (Breusch-Pagan Lagrange multiplier (LM)), PS (Pesaran Scaled LM), BSC (Bias-Corrected Scaled LM) & P-CD (Pesaran cross-section dependence (CD)).

Table 2
Results of panel unit root tests.

Var.list	First-Generation Unit Root Tests at Level							
	(Levin et al., 2002)		(Im et al., 2003)		ADF-Fisher		PP-Fisher	
	Int	Int & Tr	Int	Int & Tr	Int	Int & Tr	Int	Int & Tr
DE	9.39	4.45	11.64	7.64	0.553	1.91	1.247	5.88
FRI	5.25	9.75	−0.52	0.51	12.35	6.41	33.6***	271.1***
GDP	−4.10***	0.937	−0.64	0.530	13.28	5.84	7.084	12.52
TI	−2.24**	−0.24	−1.49*	−0.41	18.58*	14.88	8.68	3.020
BR&D	0.112	3.17	1.86	−0.066	5.97	10.12	7.33	9.52
First-Generation Unit Root Tests at First Difference								
D(DE)	1.40	2.66	−1.86**	−3.54***	28.92**	36.09***	125.4***	321.4***
D(FRI)	22.8	30.1	−1.39*	−1.028	18.04	16.29	130.8***	361.2***
D(GDP)	3.31	6.51	−0.84	−0.52	13.55	10.18	100.6***	130.5***
D(TI)	0.781	2.79	−1.24	−1.89	16.35	19.46*	63.64***	56.21***
D(BR&D)	2.26	5.44	−2.40***	−2.84***	27.20**	30.18***	73.18***	63.72***

Var.list	Second-Generation Unit Root Test			
	Level		First-Difference	
	Int	Int & Tr	Int	Int & Tr
DE	−1.452	−1.871	−4.110***	−4.276***
FRI	−1.551	−1.683	−3.991***	−4.368***
GDP	−1.959	−2.459	−4.056***	−4.128***
TI	−1.590	−2.70	−4.863***	−4.921***
BR&D	−1.695	−1.660	−4.002***	−4.523***

Note: ***, **, * is for 1%, 5% and 10% statistical significance level.

Table 3
Cointegration analysis.

Statistic	Gt	Ga	Pt	Pa
Value	−4.394***	−22.543***	−15.124***	−33.141***
Z-Value	−6.214	−4.711	−8.561	−9.781
P-Value	0.000	0.000	0.000	0.000

Note: *** is for a 1% statistical significance level.

the earlier findings of (Barro and Lee, 1996), who argue that the income of the country is vital for innovation. Factors such as infrastructure and R&D spending depend on national income. Henceforth, an increase in the income of the country improves the innovation of the G7 countries. Fourth, the results show that the financial risk index negatively affects innovation, which supports the findings of (Isik and Hassan, 2003) and (Ali et al., 2011). High financial risk leads to low expected returns, which in turn reduces the bank financing of R&D expenditures. Due to the high financial risk of firms, banks often reluctant to finance innovative ideas. Hence, high financial risk is considered an impediment in technological innovation in G7 countries. For nurturing technology through digitalization in economy and business financed R&D expenditure, G7 countries must minimize the financial risk. To sum up, digitalization in economy and R&D expenditures have significant implications for technological innovation. However, to reap the positive benefits of these factors, G7 countries need to minimize the financial risk. For robustness checks, we use the FMOLS method and results are consistent with the findings of AMG and CMG methods (Tables 4 and 5).

Table 4
Empirical results.

Variables	CMG	AMG	Signs
BR&D	0.34***	0.36***	> 0
	[0.125]	[0.101]	
DE	0.016***	0.019***	> 0
	[0.002]	[0.003]	
GDP	0.38***	0.39***	> 0
	[0.112]	[0.115]	
FRI	−0.013***	−0.018***	< 0
	[0.003]	[0.001]	
Constant	0.91***	0.80***	> 0
	[0.141]	[0.086]	
Wald-Test (CMG)	Wald-Test (AMG)	RMSE (CMG)	RMSE (AMG)
15.231***	17.761***	0.013	0.016

5. Conclusion and policy implications

Digitalization in economy plays a vital role in the economic growth of a country, and technological innovation is not achievable without digitalization and plays a significant role in affecting factor productivity. Digitalization in economy plays a significant role in affecting factor productivity and has increased over the years, particularly after the arrival of industrial revolution 4.0. The amazing performance of G7 countries in achieving high economic growth is due to an improved degree of technological innovation and other factors. In recent years, the digitalization of economies in the form of advancement in Information and Communication Technologies (ICTs) have changed the business dynamics of G7 countries. These digitalization advancements have improved G7 economies in terms of an increase in productivity, social change, and industrial development. Hence, G7 countries have a significant share in World's net wealth, improved degree of technological innovation, and at the same time, have made advancement in digitalization. This paper aims to examine the impact of digitalization in the economy on technological innovation in the presence of business financed R&D expenditures, income, and financial risk for G7 countries over the period of 1990 to 2017. This study contributes to the existing literature by examining new determining factors of innovation.

Contrary to previous studies, which use used R&D expenditure, this study uses bank financing R&D expenditure as a new determinant of technological innovation. We differentiate between total R&D expenditures and bank finance R&D expenditures. This study uses recently developed econometric approaches, which are superior to traditional first-generation econometric methods. The econometric estimation provides robust results: i) there is ample evidence of CSD and slope heterogeneity; iii) all variables are stationary at first difference; iv)

Table 5
Fully modified OLS (robustness results).

Variable	Coefficient	Std. Error	t-Statistic	Prob.
BRD	0.37****	0.051	7.25	0.000
DE	0.017***	0.002	8.50	0.000
GDP	0.35***	0.067	5.22	0.000
FRI	−0.0143***	0.001	−14.30	0.000
Constant	0.82***	0.113	7.26	0.000

technological innovation is cointegrated with its determinants such as digital economy, bank financing R&D expenditures, GDP, and financial risk; v) digital economy, bank financing R&D expenditures and financial risk are all important factors responsible for technological innovation in G7 countries; vi) except for the financial risk index, all other variables are positively related to technological innovation.

In terms of policy implications, this study offers meaningful implications for decision-makers in designing their policies related to the digital economy, bank financing, and, ultimately, technological innovation in G7 countries. There is a dire need to change the business dynamics of G7 countries. The digital economy in the form of automation of economy and artificial intelligence can help transform the economic and business structure and performance. Digitalization in economy can change the business dynamics, institutional quality, and organizational structure of these countries since the cost of innovation is significantly high for which bank finance is sufficiently required. However, due to the high financial risk of firms, banks often reluctant to finance innovative ideas. Hence, for nurturing technology through digitalization in economy and business financed R&D expenditure, financial risk must be minimized.

CRediT authorship contribution statement

Shengjun Yuan: Conceptualization, Data curation, Visualization, Investigation, Writing - review & editing. **Hammed Oluwaseyi Musibau:** Conceptualization, Methodology, Software, Formal analysis. **Sema Yılmaz Genç:** Conceptualization, Writing - review & editing. **Riffat Shaheen:** Software, Validation, Project administration, Writing - review & editing. **Anam Ameen:** Conceptualization, Methodology, Validation, Visualization, Writing - review & editing. **Zhixiong Tan:** Conceptualization, Supervision, Writing - review & editing.

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