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Uncertainty and technological innovation: evidence from developed and developing countries

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Abstract
Uncertainty will not only harm the economy but may also provide an opportunity for technological innovation. It is well established from past studies that technological innovation is a useful tool for reducing uncertainty across countries. However, it is not known whether this uncertainty can contribute to innovation across countries. Hence, in this study, we develop an empirical model to examine the impact of uncertainty on technological innovation across a global panel of both developed and developing countries over the period 2013–2018. Using generalized methods of moment (GMM), we find that uncertainty have significant negative and positive impact on technological innovation in developing and developed countries, respectively. Given these findings, the study argues that the role of uncertainty in improving technological innovation significantly varies across both developed and developing countries. Therefore, significant implications have to do with the fact that developing countries need to initiate effective action to look uncertainty as a key to unlocking opportunity, while developed countries should take into consideration that uncertainty is a viable strategy for addressing innovation ideas.

Keywords Uncertainty · Technological innovation · Developing countries: Developed countries

1 Introduction

Nowadays, everybody knows technological innovation is restructuring the World faster than ever before and benefits consumers, business and the economy as a whole. The rapid pace of technological innovation is fundamentally changing people's way

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of living and working. It affects all fields, economies and industries, including how, what and where people manufacture and distribute goods and services and not just production. Generally, technological innovation influences future growth by changing the relative value of capital, transforming economic sectors, changing organizational thinking skills and capabilities (Fagerberg et al. 2010; Ramadani et al. 2013; Martin and Leurent 2017; Dauda et al. 2019; Chege et al. 2020). This creates opportunities for governments, firms, individual, and consumers to found a new way of doing things and to develop and adopt new kinds of products, production process, business and services and organizational model. While technological innovation is considered as a major force in future growth, the rapidly growing uncertainty is likely to offer another option to strengthen technological innovation.

Theoretically, technological innovation is a process that begins with the idea generation phase, which helps to discover new opportunity for achieving new or improved product and services (Schilling and Shankar 2019). Here, uncertainty can be seen as a major source for generating new ideas, identifying and inventing new innovative technology to manage uncertainty. If a country perceives high uncertainty, it tends to embrace more innovative technologies and thus reduce the risks associated with uncertainty. For example, production or yield uncertainties due to climate change led to the discovery of innovative ideas such as Robotic technologies, Infrared sensors for crop stress detection (Infrared Thermal Imaging Technology, Remote Sensing Techniques), Weather Foresting (Doppler Radar, Weather Satellites) technologies to support the global growth of sustainable agriculture and food production (Jalonen 2012; Kalamova et al. 2012; Martin and Leurent 2017). Similarly, social uncertainty allows for financial (FinTech) technology to be secured without any effort, practically without a person's assistance where financial operations such as money transfers, deposits, loans, and investment management are carried out. Given these explanations, uncertainty seen as the key to unlocking opportunity for countries to promote development and adoption of innovation.

Besides putting a theoretical emphasis on the role of uncertainty and technological innovation, we take a very simple look at the real-world relationship between uncertainty and innovation for developed and developing countries over one decade. Figures 1 and 2 share different views on the relationship between uncertainty and innovation between developed and developing countries. For developed countries, higher uncertainty tended to lead a higher level of technological innovation while developing countries with higher uncertainty rate are experiencing a lower level of innovation. Given that developing countries seem unable to foster technological innovation in a situation of a high degree of uncertainty, which is contrary to our discussion above. For example, developed countries that score high on uncertainty tend to adopt more innovative technologies and thus minimize the risks associated with uncertainty relative to developing countries. Therefore, the impact of uncertainty on technological innovation remains highly ambiguous and still unanswered conclusively.

This paper proceeds as follows. Section 2 reviews the relevant literature. The effect of uncertainty on the technological innovation is modeled in Sect. 3. Section 4 discusses econometric modeling framework with empirical analyses and Sect. 5 concludes with a summary of the main findings and policy implication.

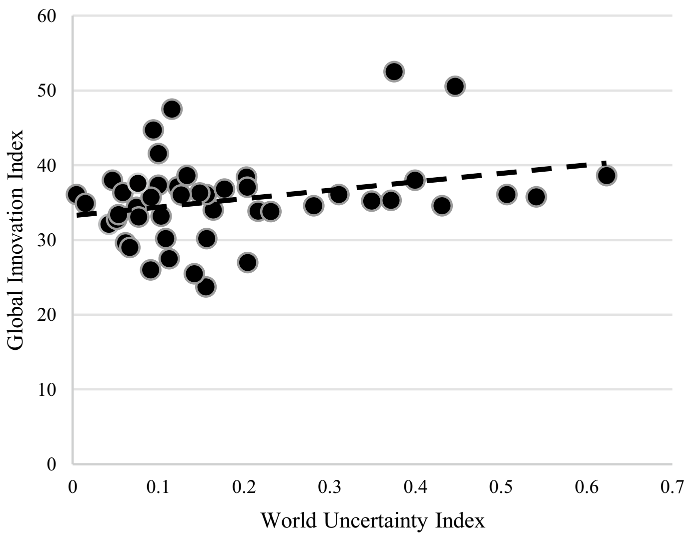

Fig. 1 Uncertainty versus technological innovation of developed countries *Source* World Intellectual Property Organization (2019) & Hites Ahir (International Monetary Fund), Nicholas Bloom (Stanford University) and Davide Furceri (International Monetary Fund) (2020)

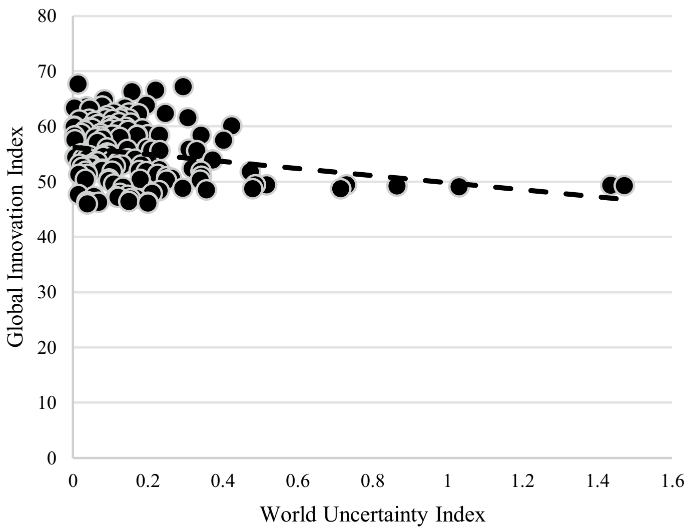

Fig. 2 Uncertainty versus technological innovation of developing countries *Source* World Intellectual Property Organization (2019) & Hites Ahir (International Monetary Fund), Nicholas Bloom (Stanford University) and Davide Furceri (International Monetary Fund) (2020)

2 Literature review

In respect of past studies, several noticeable factors affected technological innovation have been identified such as corruption (Leff 1964; Lui 1985; Anokhin and Schulze 2009; Nguyen et al. 2016; Xu and Yano 2017; Dincer 2018; Riaz and Cantner 2019), inequality (Falkinger 1994; Zweimüller 2000; Pieroni and Pompei 2008a, b; Tselios 2011; Coccia 2014a, b), education (Edquist 1997; Furman et al. 2002; Lundvall et al. 2002; Chen and Puttitanun 2005; Varsakelis 2006; Serdyukov 2017) research and development expenditures (Acs et al. 2002; Furman et al. 2002; Bhattacharya and Bloch 2004; Schneider 2005; Akcali and Sismanoglu 2015, Coccia 2017a, b; Coccia 2019), corruption (Leff 1964; Lui 1985; Nguyen et al. 2016; Riaz and Cantner 2019; Gan and Xu 2019), climate change (Coccia 2015), governance (Coccia 2017a, b; Chen et al. 2020; Könnölä et al. 2021; Chen 2021), population growth (Coccia 2014a, b). As population growth causes resource management and socioeconomic system problems, an increase in the number of people associated with higher levels of democracy, good economic governance and institutions, and the accumulation of highly skilled human capital leads to more sustainable patterns of technological innovation. Due to the large number of publications on technological innovation, this review focuses only on selected works that presents factors influencing and limiting technology innovation development. It also refers to the impact of uncertainty on technological innovation.

Many scholars have debated the impact of technological innovation in the context of corruption (Leff 1964; Lui 1985; Anokhin and Schulze 2009; Nguyen et al. 2016; Xu and Yano 2017; Dincer 2018; Riaz and Cantner 2019; Gan and Xu 2019). Anokhin and Schulze (2009) for 64 countries; Nguyen et al. (2016) for Vietnam; Xu and Yano (2017) for China; Dincer (2018) for the USA; Riaz and Cantner (2019) for developing and emerging countries assessed the effects of corruption on technological innovation. Studies on corruption and innovation are primarily rooted in empirical indicates that corruption impede country technological innovation activities. Corruption negatively affects innovative activities due to a lack of property rights institutions, making innovation vulnerable to predation. Thereby, the country becomes less attractive, and the rate of innovative development slows down. Besides that, Myrdal (1968), De Waldemar (2012), Yang (2017) and Dincer and Fredriksson (2018) evolve around the sanding the wheels hypotheses observe that countries with more corruption tend to have high transactional costs and leading to the misallocation of resources and placing barriers to invest in innovative activities. On the other hand, Leff (1964), Lui (1985), Nguyen et al. (2016), and Riaz and Cantner (2019) identifying corruption as the greasing the wheels that are attractive for innovations. Corruption is desirable for innovative developments due to the loopholes in the legal system that help to ease and speed up innovative technological processes. Therefore, in the past studies, there seems to be no consensus about how corruption affects the technological innovation.

According to Falkinger (1994), Zweimüller (2000), Pieroni and Pompei (2008a, b), Tselios (2011), and Coccia (2014a, b) inequality affects technological innovation via two channels. The first strand of the previous studies relates to the inequality and innovation refer to the role of inequality in improving the technology by innovation. Falkinger (1994) and Tselios (2011) argue that inequality can be important determinants of innovation if the distribution of income influences product demand. The increased disparity between rich and poor raises demand for the innovative products and services, thus forcing the country to invest in innovative activities and fostering technological innovation. The reason for this is that the rate of demand for the technological aspect of a good or services increases with higher income of rich people compared to poor people. Therefore, it pushes the country toward technological innovation. Second, Johnson (1997), Zweimüller (2000) and Pieroni and Pompei (2008a, b) have shown contrasting results that increased income disparity slow technology innovation process. Johnson (1997), Zweimüller (2000) and Pieroni and Pompei (2008a, b) have shown that higher inequality leads to less favorable conditions for innovation by lowering the level of gross domestic product per capita. Given the discussion of past studies, income inequality affects technological innovation significantly. Furthermore, Edquist (1997), Furman et al. (2002), Lundvall et al. (2002), Chen and Puttitanun (2005), Varsakelis (2006), and Serdyukov (2017) believe that education can attract countries to accelerate product and process innovation. Edquist (1997), Furman et al. (2002), Lundvall et al. (2002), Chen and Puttitanun (2005), Varsakelis (2006), Vieluf et al. (2012), and Serdyukov (2017) find that education specifically affects the country-level innovations. Education is structured to provide people with knowledge, skills, and motivation to adopt technological innovation and therefore facilitates innovative activity. For example, a few descriptive works of literature on the impact of education on technology in India, Brazil, and Afghanistan indicates that higher education can be beneficial to innovation growth because it provides progressive ideas on innovation and prepares people with realistic awareness that the world is moving toward technological innovation. Such studies, therefore, show that growing education can help promote technological innovation.

Regarding the factors influencing technological innovation, some scholars (Acs et al. 2002; Furman et al. 2002; Bhattacharya and Bloch 2004; Schneider 2005; Akcali and Sismanoglu 2015; Coccia 2017a, b) show that the level of innovation in the investigated countries is dependent on research and development expenditures. A review of the literature indicates that research and development is regularly examined by motivations theory (Acs et al. 2002; Furman et al. 2002; Bhattacharya and Bloch 2004; Schneider 2005; Akcali and Sismanoglu 2015). Research and development (R&D) refer to innovative activities undertaken by countries in creating or enhancing new goods or products or improving existing ones. Thereby R&D is an essential input for innovation because it affects country innovative behavior. R&D is a necessary condition for the development of innovative technological products and services because it creates incentives for new technologies which subsequently leads to more adaptive to technological innovation. Hence, higher research and development expenditures leads to developments in technological innovations.

Increased research and development expenditures can accommodate the degree of innovation that stimulates technological innovation due to greater willingness to utilize and enhance innovation and support innovative ideas, combined with higher education, which has resulted in higher innovation outcomes. While these factors allowing an innovative environment, the rapidly growing uncertainty is likely to offer another option to strengthen technological innovation. Schneider (2005), Chen and Puttitanun (2005), Bhattacharya et al. (2017), Coccia (2019), and He et al. (2020) are among the few studies examining the effects of uncertainty in innovative activity. Schneider (2005) and Chen and Puttitanun (2005) indicate that uncertainty is a major source of innovation development by modifying existing technologies, operating processes, and inventing new technologies, in particular, to overcome the uncertainty. Understanding the nature of uncertainty can create the need and tremendous opportunity for technological innovation which in turn help to manage current and future uncertainty. Dearing (2000), Jalonen and Lehtonen (2011), Wang et al. (2017), and Bhattacharya et al. (2017), on the other hand, has been argued that uncertainty traditionally associated with obstacles to innovation, which lower innovative probabilities. Uncertainty, including technological uncertainty (the possibility of choosing alternative (future) technological options), resource uncertainty (amount and availability of raw material, human and financial resource needed), and competitive uncertainty (competing technological options) may delay or even abandon innovation activities and performance.

Although there is a literature on how uncertainty affect innovation, the relationship between uncertainty and innovative activity are highly questionable and may be inaccurate. The basic idea is that countries have two options, either to stimulate a country to engage in technological innovation or can see as obstacles leading to lower innovation. A high level of uncertainty refers to the issue in which countries are accelerating the pace of technological innovation development and adoption. If a country perceives high uncertainty, it tends to embrace more innovative technologies and thus reduce the risks associated with uncertainty. There is also a possibility where, in a situation of high uncertainty, countries have not been able to promote technological innovation. Too many uncertainties may hinder the ability of countries to turn uncertainty into opportunity, to innovate and thus hinder the transition to technology. Given the mixed scenario and contrast relation, this study opts to examine the relationship between uncertainty and technological innovation for developed and developing countries. Examining the linkage for developed and developing, which face the lower and higher level of uncertainty seems to provide a better and more insightful direction to the technology experts.

3 Methodology

3.1 Data and measures of variables

This study used secondary data in which the data comes from different kind of sources because secondary data are more reliable and saves time. This study used a balanced panel data for 40 developing and 51 developed countries from 2013 to

Table 1 List of variables, descriptions and sources

Variables	Proxy	Descriptions	Sources
Technological innovation	World Innovation Index	The Global Innovation Index (GII) provides detailed metrics about the innovation performance of 131 countries and economies around the world. Its 80 indicators explore a broad vision of innovation, including political environment, education, infrastructure, and business sophistication	World Intellectual Property Organization (2019)
Corruption	Control of Corruption (Index)	Control of Corruption captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests	World Bank (2019)
Income inequality	Gini Index	The Gini index is a measure of statistical dispersion intended to represent the income inequality or wealth inequality within a nation or any other group of people	
Education	School enrollment, primary (% gross) School enrollment, Secondary (% gross) School enrollment, tertiary (% gross)	Gross enrollment ratio is the ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the level of education shown	
Research and development	Research and development expenditure (% of GDP)	Gross domestic expenditures on research and development (R&D), expressed as a percent of GDP. They include both capital and current expenditures in the four main sectors: Business enterprise, Government, Higher education and Private nonprofit. R&D covers basic research, applied research, and experimental development	

Table 1 (continued)

Variables	Proxy	Descriptions	Sources
Uncertainty	World Uncertainty Index	The World Uncertainty Index is a new measure that tracks uncertainty across the globe by text mining the country reports of the Economist Intelligence Unit	Hites Ahir (International Monetary Fund), Nicholas Bloom (Stanford University) and (International Monetary Fund)

2018 used to examines the role of uncertainty in explaining technological innovation. Additionally, the present study used various data sources to obtain the datasets on dependent and independent variables of developed and developing countries from 2013 to 2018. Table 1 provides a summary of each variable.

3.2 Models and data analysis

This study extends the model of Zweimüller (2000), Pieroni and Pompei (2008a, b), and Tselios (2011) by including the world uncertainty index as determinants of technological innovation. This study also predicts that the presence of uncertainty may have significant effects on technological innovation. Schneider (2005) and Chen and Puttitanun (2005) have shown the possibility that higher levels of uncertainty tend to increase the level of innovation. In contrast, previous studies such as Dearing (2000) and Jalonen and Lehtonen (2011) found that uncertainty as a hindrance to innovation. In short, this study can synthesize from the past studies that uncertainty significantly affects innovative activities. Also, there is a lack of empirical studies that incorporated technological innovation. Empirical evidence is therefore required to examine the impact of uncertainty on technological innovation. The selection of control variables is built on past studies of Schneider (2005), Tselios (2011), Akcali and Sismanoglu (2015), Nguyen et al. (2016), Nguyen et al. (2016), Xu and Yano (2017), Serdyukov (2017), Dincer (2018), Riaz and Cantner (2019), and Riaz and Cantner (2019) by incorporating corruption, income inequality, research and development expenditures and education. The model form used in study is presented as follow:

$$\mathrm{TI} = f(\mathrm{CORP}, \mathrm{IE}, \mathrm{EDU}, \mathrm{RD}, \mathrm{UNCER}) \tag{1}$$

where CORP is corruption, IE is income inequality, EDU is education and RD is research and development and UNCER is uncertainty. Econometrically, Eq. (2) in logarithmic form can be expressed as follows:

$$\ln \mathrm{TI}_{i,t} = \alpha_0 + \alpha_1 \ln \mathrm{CORP}_{i,t} + \alpha_2 \ln \mathrm{IE}_{i,t} + \alpha_3 \ln \mathrm{EDU}_{i,t} + \alpha_4 \ln \mathrm{RD}_{i,t} + \alpha_5 \ln \mathrm{UNCER}_{i,t} + \varepsilon_{i,t} \tag{2}$$

where the prefix "ln" represents the natural logarithm, $\alpha_1, \alpha_2, \alpha_3, \alpha_4$, and, α_5 are the slope parameters to be estimated subscripts i and t refers to country and year, respectively, and ε is an error term. $\alpha_1, \alpha_2, \alpha_5$ are expected to be significant and the impact of α_3, and α_4 on innovation are expected to be positive.

On the basis of a short period employed in this study, this study estimates Eq. (3) by using GMM estimator. Hence, the modified dynamic panel data model under GMM can be simplified and shown as in Eq. (3):

$$\ln \mathrm{TI}_{i,t} = \partial \ln \mathrm{TI}_{i,t-1} + \beta \ln X_{i,t} + \varepsilon_{i,t} + \gamma_i \tag{3}$$

Equation (3) represents the model at the level where the $\ln \mathrm{TI}_{i,t}$ depends on the vector of determinants, $\ln X_{i,t}$ (i.e., corruption, income inequality, education, research and development, and uncertainty), and γ_i a country-specific effect.

Initially, the first-difference GMM estimation applied to eliminates the country-specific effect by transforming Eq. (3) into the first difference. This can be expressed as

$$\Delta \ln \mathrm{TI}_{i,t} = \partial \Delta \ln \mathrm{TI}_{i,t-1} + \beta \Delta \ln X_{i,t} + \Delta \varepsilon_{i,t} \tag{4}$$

Although the country-specific effect was eliminated by Eq. (4), the endogeneity issue still existed because a number of explanatory variables may be endogenous naturally. The problem of endogeneity usually relates to the presence of a correlation between explanatory variables and the error term. To resolve the endogeneity problem, Arellano and Bovver (1995) proposed the use of the lagged-level explanatory variables as instrumental variables, since by construction these variables are not correlated with the error term. Hence, we derive the following equations, as follows:

$$\begin{aligned} E\left[\left(\ln \mathrm{TI}_{i,t-s}\right)\left(\Delta\varepsilon_{i,t}\right)\right] &= 0 \; for \; s \geq 2, \; t = 3, \ldots T \\ E\left[\left(\ln X_{i,t-s}\right)\left(\Delta\varepsilon_{i,t}\right)\right] &= 0 \; for \; s \geq 2, \; t = 3, \ldots T \end{aligned} \tag{5}$$

The estimation, therefore, eliminated endogeneity.

4 Results and discussion

We begin our analysis by looking at the descriptive analysis before continuing to estimating the panel data technique. The descriptive statistics for the independent and dependent variables are shown in Table 2. We find that the mean of technological innovation for the period is recorded as 4.546 and uncertainty during the same period is 4.054. The maximum technological innovation is 5.475 while the minimum value is 2.272. For uncertainty, the maximum value is 5.475 and the minimum value is 2.272. Particularly, the research and development have the highest mean, maximum and minimum value of 7.535, 6.826, and 3.836, respectively. Additionally, the standard deviation displays that corruption has the greatest variation of 0.410 and followed by research and development, education, income inequality, uncertainty, and technological innovation.

Here, we discuss results of the aggregated analysis in which we use we split the sample in developed (40 countries) and developing countries (51countries). Table 3 captures the results of two-step GMM estimator for developed and developing countries, respectively. In the dynamic panel model, the Hansen test of over-identifying restrictions and Arellano–Bond (AR) test are employed for the

Table 2 Descriptive statistics

	ln TI	ln CORP	ln IE	ln EDU	ln RD	ln UNCER
Mean	4.546	3.272	4.569	4.564	7.535	4.054
Max	5.862	6.176	6.326	6.212	6.826	5.475
Min	3.120	2.261	2.879	3.120	3.836	2.272
Std. dev.	0.142	0.410	0.255	0.242	0.292	0.218

Table 3 Regression Analysis [DV = ln TI]

	Developing countries		Developed countries	
	DIF-GMM	SYS-GMM	DIF-GMM	SYS-GMM
ln TI_{t-1}	0.9106*** (7.88)	0.1403*** (5.16)	0.5676*** (2.47)	0.9832*** (8.31)
ln CORP	−0.0230* (−1.72)	−0.0439*** (−3.40)	−0.0293* (−1.81)	−0.0621* (−2.07)
ln IE	−0.0107** (−2.15)	−0.0283** (−2.22)	−0.0303 (−2.43)	−0.0939** (−2.14)
ln EDU	0.0214*** (2.55)	0.0727** (2.11)	1.2610** (3.28)	0.1157*** (2.81)
ln RD	−0.0662*** (−4.44)	−0.0161* (−1.82)	1.0304*** (3.13)	1.3776*** (3.67)
ln UNCER	−0.0110* (−1.95)	−0.0244** (−2.23)	0.2517** (2.10)	0.1223*** (3.003)
Model criteria				
Hansen	0.872	0.812	0.318	0.291
AR (1)	0.002***	0.043**	0.013**	0.016**
AR (2)	0.668	0.119	0.213	0.145
Difference-Hansen		0.947		0.967
F-test	142.87***	338.63***	192.07***	190.53***
#instruments	26	35	32	30
#Groups	40	40	51	51

Asterisks *, **, and *** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in () stand for *t*- statistics. The values of the Hansen and AR tests stand for the *p*-value. The model is estimated using the two-step model with robust estimation

adequacy of the model and appropriateness of estimation method. It is observed that all *p*-values of the Hansen test is higher than significance level, thereby signifying the validity of the instruments. As can be seen from Table 3, the outcome of *p*-value of AR (1) in first difference rejects the null hypothesis that there is autocorrelation while AR (2) does not reject the null hypothesis. Lastly, the *p*-value of the Scalar static in GMM approach is greater than the significance level and can be confident that system GMM achieves greater efficiency than difference GMM for the model. Due to that this study focuses on SYS-GMM two-step for both developed and developing countries.

As shown in Table 3, the explanatory variables such as education, corruption, and income inequality carry the expected signs for developed and developing countries. In the dynamic model of developed and developing countries, education is having significant positive effect on technological innovation. For example, the coefficient 0.0727 indicate that every one percent increase in education is associated with an average increase in innovation by 0.0727%. This is in in-line with Furman et al. (2002), Lundvall et al. (2002), Chen and Puttitanun (2005), Varsakelis (2006), Vieluf et al. (2012), and Serdyukov (2017), who argue that education is an important variable that attracts innovation in both developing and developed countries. For instance, education encourages the innovation necessary for countries by increasing human cognitions levels and providing higher insight into how respond better and quickly to the new things. This may be leads to innovative consumers who adopt and accept the new product, thereby stimulate firm's technological innovation level.

For developed and developing countries, corruption has shown negative and significant impact on technological innovation. The negative coefficient of the corruption confirms the notion that higher level of corruption reduces opportunities for country to engage in innovation. The results suggest that a one percent increase in corruption decreases technological innovation by 0.0439% and 0.0621% for the developing and developed countries. According to a number of studies, when a firm must pay bribes to manage innovation activities, the cost of doing so rises, potentially discouraging firms from doing so (Myrdal 1968; De Waldemar 2012; Yang 2017; Dincer and Fredriksson 2018). In contrast to the findings of Leff (1964), Lui (1985), Nguyen et al. (2016), Gan and Xu (2019) and Riaz and Cantner (2019), detecting corruption can increase the degree of innovation by reducing stiff barriers to investment and fostering innovation. Thus, the corruption variable, like Bloom et al. (2019), Nguyen et al. (2016), and Riaz and Cantner (2019), has a detrimental impact on innovation.

Regarding the independent variable for income inequality in Table 3, it is observed that the increase of inequality negatively contributes to technological innovation, confirming the findings of Johnson (1997), Zweimüller (2000) and Pieroni and Pompei (2008a, b). Estimates for developing and developed countries imply that a one percentage point increase in income inequality is connected with 0.0283 and 0.0939% increases in technological innovation, respectively. The reason is that the higher inequality reduces the desired pay for innovative products because some poor are already satisfied with non-innovative goods. This suggests that the unequal distribution of income decreases the demand for non-innovative products and decreases incentives for technological innovation.

Furthermore, the GMM result shows that research and development expenditures have a negative effect on innovation for developing countries, whereas that for the developed countries reveals the positive impact. According to coefficient estimates, a one percent increase in research and expenditure results in a 0.0161% decrease in technological innovation in developing countries, but a one percent increase in research and expenditure results in a 1.3776% reduction in technological innovation in developed countries. These results support the findings of Schneider (2005), Akcali and Sismanoglu (2015) and Coccia (2019), suggesting that developing countries' investments in research and development are ineffective in promoting technological innovation. In the case of developed countries, the findings show that research and development play an essential part in the technological innovation process, leading to increased capabilities to engage in innovative activities (Schneider 2005; Akcali and Sismanoglu 2015).

The main takeaways of the paper are uncertainty, which indicates that uncertainty have significant negative impact on technological innovation for developing countries. More precisely, a one percent rise in uncertainty declines technological innovation by 0.0244%. Our findings for the developing countries are similar to those of past studies (Dearing 2000; Jalonen and Lehtonen 2011; Coccia 2017a, b; Bhattacharya et al. 2017; Wang et al. 2017). In two ways, uncertainty can be significantly and negatively related to technological innovation. Firstly, rising uncertainty in developing countries are more likely associated with negative effects on economic growth appear to raise difficulties in strengthening innovation activities. For example, low growth in gross domestic product narrows the overall size of the economy and weakens fiscal condition leading to lower government expenditure and high taxes on innovative processes, which could link to reduced incentives to innovate. Secondly, high uncertainty also adversely affect innovation by altering firm decision to engage in innovative activities. This is because uncertainty reduces a company's financial capacity, causing it to postpone investments in innovative activities, discourage the development of new goods or the existing ones, and innovate. As a result, in developing countries, uncertainty becomes an impediment to technical innovation and similar to Dearing's (2000) and Jalonen and Lehtonen (2011).

On the contrary, it appeared to generate innovation in the developed countries where a one percent rise in uncertainty stimulates innovation by 0.1223%. For developed countries, the results suggest that uncertainty has a positive impact on their innovation level. This study's findings are consistent with those of Schneider (2005) Chen and Puttitanun (2005) and He et al. (2020), who contend that uncertainty can encourage a country to engage in or invest in innovative activities. One finds that managing uncertainty contributes to further innovation, which allows us to turn uncertainty into a solution for problems. It seems that creating or implementing new ideas or approaches along the path of uncertainty is not only to minimize or remove uncertainty but also to promote innovation.

For robustness purpose, we have also conducted the GMM analysis with additional explanatory variables, namely foreign direct investment (*FDI*) and trade (*TR*). As it is possible to observe in Table 4, foreign direct investment, and trade can be seen to improve innovation in both developed and developing countries. Foreign direct investment is positively and significantly linked to technical innovation, with a one percent increase in *FDI* resulting in a 0.0118% and 0.4698% rise in the level of innovation in developed and developing nations, respectively. *FDI* promotes innovation activities of countries by expanding access to innovative technologies and resources in countries. This may increase their capacity to invest in research and development and process innovations that results either in a new kind of product or a better process for producing an existing product. Our findings are in-line with past studies. While trade also exerts a positive impact on innovations. The findings reveal that one percent increase in *TR*, leads to 0.0490% increase in technological innovation. Meanwhile, consistent with the main findings, uncertainty contributes to increasing innovations in developed countries, but it is not effective in motivating innovation in developing countries.

Table 4 Regression analysis for additional controlled variables [DV = ln TI]

	Developing countries				Developed countries			
	DIF-GMM		SYS-GMM		DIF-GMM		SYS-GMM	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
ln TI_{t-1}	0.8684*** (6.48)	0.7525*** (5.14)	0.1331*** (3.83)	0.2299*** (3.91)	0.5454*** (2.95)	0.4658*** (5.28)	0.9429*** (9.73)	0.9724*** (8.74)
ln CORP	−0.0449* (−2.05)	−0.0861*** (−3.19)	−0.0309** (−2.19)	−0.0409*** (−2.94)	−0.2178*** (−2.71)	−0.0567*** (−2.48)	−0.0623** (−2.26)	−0.0507* (−1.93)
ln IE	−0.0266** (−2.11)	−0.0518*** (−3.09)	−0.0101* (−1.90)	−0.0119** (−2.13)	−0.0434* (−2.04)	−0.0170* (−2.06)	−0.0817*** (−2.75)	−0.0177* (1.82)
ln EDU	0.0876** (2.36)	0.0604** (2.19)	0.0235* (2.05)	0.0192* (2.09)	0.1443* (1.87)	0.5664*** (3.35)	0.2643** (2.38)	0.3950*** (4.16)
ln RD	−0.0144* (−1.96)	−0.0760*** (−2.46)	−0.0100* (−1.82)	−0.0669*** (−2.59)	0.9197*** (2.40)	0.2169*** (2.73)	0.8011*** (3.37)	0.1215** (2.20)
ln UNCER	−0.0155* (−2.05)	−0.0263** (−2.19)	−0.0150* (−2.08)	−0.0254*** (−2.37)	0.2422** (2.12)	0.2927** (2.25)	0.1196** (2.10)	0.1100** (2.17)
ln TR	0.0972*** (3.02)	–	0.0521** (2.25)	–	0.1443* (1.98)	–	0.0490* (1.85)	–
ln FDI	–	0.0138* (1.89)	–	0.0118* (1.85)	–	0.1575** (2.11)	–	0.4698*** (3.80)
Model criteria								
Hansen	0.858	0.983	0.728	0.6330	0.596	0.621	0.396	0.751
AR (1)	0.007	0.011	0.013	0.073	0.096	0.057	0.017	0.008
AR (2)	0.718	0.857	0.393	0.720	0.143	0.155	0.263	0.249
Difference-Hansen			0.993	0.938			0.924	0.986
F-test								
#instruments	36	30	32	30	36	30	35	33

Table 4 (continued)

	Developing countries				Developed countries			
	DIF-GMM		SYS-GMM		DIF-GMM		SYS-GMM	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
#Groups	40	40	40	40	51	51	51	51

Asterisks *, **, and *** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in () stand for *t*- statistics. The values of the Hansen and AR tests stand for the *p*-value. The model is estimated using the two-step model with robust estimation

5 Conclusion

In this research, the relationship among the uncertainty and innovation in a panel of developed and developing countries with the most recent dataset from 2013 to 2018 were examined. The generalized method of moments estimation is utilized to scrutinize the association among the study core variables. The examined findings of the GMM specify that the uncertainty have a significant impact on innovation. One observes that uncertainty present different impact on developed and developing countries. The results indicate that in developed countries the effect of uncertainty on innovation is positive, while in developing countries the impact of uncertainty on innovation is negative. Besides, the results from the robustness tests lend support to this view that developed countries are more likely engage in innovation activities than developing countries during uncertainty times. Therefore, the findings confirm that uncertainty provides positive support for developed countries, whereas developing countries harms from uncertainty.

The study's findings have substantial policy implications. The response of uncertainty to technological innovation is asymmetric in both developing and developed countries; therefore, policymakers should develop policies that account for both the negative and positive impacts. Governments should enable developing countries' understanding of uncertainty to improve the ability of a country to transform or convert the uncertainty into innovations. To increase understanding, communication of information around uncertainty needs to strengthen as well as people's knowledge and skills in decision making required to overcome these challenges. Moreover, governments and other agencies need to provide financial aid to the developing countries for transforming uncertainty into opportunity. This is because developing countries usually seek additional funds to handle uncertainty, thus discouraging countries from converting increased uncertainty into incentives that promote innovation. Furthermore, it is widely accepted that collaboration and mutual combination of different policy tools between developed and developing countries is also critical in minimizing cost-management uncertainties and shifting their challenges to innovation. With this cooperation, developing countries can be encouraged to create, developing and diffuse new products or process, particularly during the uncertainty times.

This analysis limits in sample and variables in empirical analysis. Our primary goal is to examine the impact of uncertainty on technological innovation in developing and developed countries, but we measure uncertainty without regard to different types of uncertainty. Besides, the technological development of innovation is influenced by numerous factors associated with uncertainty, which are not addressed in this study. As a result, in future research, authors will need to clarify the influence of technological innovation by delving deeper into specific types of uncertainty and the factors related to uncertainty.

Appendix

See Table 5.

Table 5 List of developed and developing countries

No.	Country	No.	Country	No.	Country	No.	Country
1	Albania	31	Egypt, Arab Rep	61	Mali	91	Thailand
2	Algeria	32	Equatorial Guinea	62	Mauritania	92	Togo
3	Argentina	33	Ethiopia	63	Mauritius	93	Tunisia
4	Australia	34	Fiji	64	Mexico	94	Turkey
5	Austria	35	Finland	65	Morocco	95	UK
6	Bangladesh	36	France	66	Mozambique	96	USA
7	Belgium	37	Gabon	67	Myanmar	97	Uruguay
8	Belize	38	Gambia, The	68	Namibia	98	Zambia
9	Benin	39	Germany	69	Nepal	99	Zimbabwe
10	Bolivia	40	Ghana	70	Netherlands		
11	Botswana	41	Greece	71	Nicaragua		
12	Brazil	42	Grenada	72	Nigeria		
13	Bulgaria	43	Guinea-Bissau	73	Norway		
14	Burkina Faso	44	Guyana	74	Pakistan		
15	Cabo Verde	45	Honduras	75	Panama		
16	Cameroon	46	Hong Kong	76	Paraguay		
17	Canada	47	Iceland	77	Peru		
18	Central African Republic	48	India	78	Philippines		
19	Chile	49	Ireland	79	Portugal		
20	China	50	Italy	80	Russian Federation		
21	Colombia	51	Jamaica	81	Rwanda		
22	Comoros	52	Japan	82	Saudi Arabia		
23	Congo, Dem. Rep	53	Jordan	83	Senegal		
24	Costa Rica	54	Kenya	84	Singapore		
25	Cote d'Ivoire	55	Korea, Rep	85	South Africa		
26	Cyprus	56	Lesotho	86	Spain		
27	Denmark	57	Liberia	87	Sri Lanka		
28	Dominica	58	Madagascar	88	Swaziland		
29	Dominican Republic	59	Malawi	89	Sweden		
30	Ecuador	60	Malaysia	90	Switzerland		

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