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Does global economic reform accentuate technological innovation? A comparative evidence around the world

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ABSTRACT

Technology innovation improves efficiency, gives society new and enhanced goods and services through economic reform, and raises their living conditions. This study examined the impact of economic reform on technological innovation using the system generalised method of moments and panel quantile regressions to account for simultaneity and reverse causality. The empirical findings conclude that economic reform significantly impacted technological innovation in 79 nations from 1995 to 2017. More importantly, we verify the positive effect of economic reform on technological innovation by addressing endogenous and robustness checks *via* various methods and sub-samples. Furthermore, the mechanism of this relationship was explored. Therefore, the research findings offer an alternative method for national "gove'nments to promote innovation output by reinforcing government effectiveness, financia" sec'or development, and the degree of democracy transparency. Finally, economic proposals are discussed based on the findings and estimation strategies.

HIGHLIGHTS

- The study examines the impacts of economic reforms on technological innovation in a panel of 79 economies over 1995–2017.
- Using GMM and panel quantile regressions, empirical findings indicate that economic reforms promote technological innovations.
- The positive effect of economic reforms on innovation operates through government effectiveness, financial development, and democracy.
- Intellectual Patent Protection Act controls inadequate competitiveness and preserves a fair market climate.

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1. Introduction

Technological innovation is increasingly significant in developing leading industrial economies (Borsh, 2021). This brought several stimuli beyond the firm that influence an industry's innovation potential and encouragement. Maintaining the stimulation of sustainable development investment becomes vital. Many of these debates emphasised the critical role of innovation, making technological progress remain a primary driver of economic development (Aghion & Howitt, 1992; Ekins et al., 2014). The technological innovation in this research context is the trademark and patent application brands that distinguish explicitly between a single undertaking's goods or services and those of another (WIPO, 2015). Diverse empirical studies (Freeman & Soete, 2012; Hudson & Minea, 2013; Pradhan et al., 2016) have revealed that innovation acts as a major determinant of economic growth because of its direct impact on production processes through the improved productivity and efficiency allocation within the economy, succeeding the endogenous growth models of Romer (1990) and Nair et al. (2020). In addition, new scientific findings and technical advances help companies enhance their production and efficiency, and explore new 'disruptive technologies', giving a competitive advantage in their market.

Furthermore, after reviewing the previous empirical study, we find that technological progress is believed to be mainly influenced by human capital, the total number of the labour force (Marino et al., 2016; Perri & Peruffo, 2016; Romer, 1992), etc. Other studies also pay attention to different factors such as government policy (Flanagan et al., 2011), political ideology (Wang et al., 2019), corruption (Wen et al., 2020), stock liquidity (Brown & Floros, 2012; J. Wen et al., 2018), and uncertainty (Bloom et al., 2007; Xu et al., 2019), and a more recent study focused on globalisation (Zheng et al., 2019), renewables and energy efficiency (Wen et al., 2022), and economics of natural disaster (Okolo & Wen, 2022). While empirical studies extensively discussed the determinant of technical progress, empirical literature on the effect of economic reform policies on technological progress is deficient. Economic reforms are policies that allow for greater freedom in economic metrics monitored and likely to stimulate development and innovations. This is because growth and innovation are crucial in producing greater chances for individuals to develop themselves economically, eliminate poverty, and build enduring prosperity. As a vital part of nations' competitiveness, technical innovation lies at the core of macroeconomic stability and economic growth (Kogan et al., 2017; Xu et al., 2019). Thus, it becomes necessary to explore how reform policies affect technological innovation. The literature has shown that the architecture of the reforms has a beneficial impact on economic growth and efficiency (Eicher & Schreiber, 2010; Havrylyshyn & van Rooden, 2003; Jalilian et al., 2007; Nicoletti & Scarpetta, 2003). This corresponds to the idea that greater economic freedom is correlated with capital markets (Hafer, 2013b), which motivates business innovation outcomes (Hsu et al., 2014). As a result, we hope this research will fill a void in the literature.

Therefore, this research aims to answer the following question: How do economic reform policies impact technological innovations and the channel of mechanisms? There are several reasons why economic reform can promote technical innovation. Economic models suggest that measures regarding economic reform policies can impact

resource efficiency and productivity. Greater economic reform policies through economic freedom can translate into higher income, more innovation, and faster societal progress. Therefore, technological innovation and growth depend on the availability of resources, research and development, competition among businesses, trade, foreign direct investment, and the protection of individual rights (Hicks et al., 1974). Economic reform is designed to strengthen the regulatory impacts on innovation performance (Blind, 2016; Blind et al., 2017). They seek to enhance market efficiency—which impacts the creative process—in supplying products and services (Hernandez, 2019). In addition, economic reform governs the practical operation of the public and private sectors, providing some necessary conditions for technological growth through investment, finance, trade, etc. Therefore, these policies are entirely responsive to changes in their economic, social, and technological milieus. Improving economic reform in the industrial and service sectors is essential to developing and disseminating new technologies such as the internet, automated teller machines, and optical scanners in supermarkets. Therefore, economic reform aims to reduce costs, improve efficiency, inspire competition, and stimulate innovation in all areas (Ashford & Hall, 2011). However, this must be accomplished without jeopardising fair market transactions, environmental protection, or government monitoring of private-sector operations. Reform policies are also contentious when redistributing the costs of government policies among economic players and changing current protection mechanisms, whether for businesses or consumers. Nevertheless, reforms in the economic realm can aid in reserving a certain amount of openness in product marketplaces, which is vital for research and innovation. In addition, reforms can impose technological requirements on companies and serve as a focal mechanism for their social research activities. Therefore, economic reform is aimed as a potent catalyst for further innovation. Governments in economically free countries allow for the free movement of labour, capital, and other resources, and refrain from restricting freedom in excess of what is required to uphold and protect democracy (Miller et al., 2019). According to the economic freedom index, 90 nations (50%) provide organisational circumstances in which private enterprises have at least a respectable degree of economic freedom to acquire assets and success. Furthermore, economic reform policies are one of the major determinants of technological innovation and growth. As a result, there is a compelling case for investigating the influence of economic reform policy on technical innovativeness. However, there is no empirical evidence between economic reform policies with technical innovation and their channels of mechanisms. The research seeks to address these concerns. The existing literature has these main gaps. The first is the nature of the links between economic reform and technical advancement. For example, most past research has concentrated on the causal link between structural reform and economic growth but not on the influence of economic reform policies on technology innovativeness or how it may accomplish this aim. An inability to assess conditional elements is another problem that may exacerbate the effect of reform policies on innovation. Consequently, this research provides a channel mechanism (financial development, government efficiency, and democracy) using economic reform to promote technological innovation. The net benefits of innovation are then sorted between unconditional and conditional effects. No research on this issue has been done worldwide.

This research adds to the empirical literature by examining the direct effect of economic reform on technological innovation (measured by trademark and patent) from 79 nations, including OECD and non-OECD, European, top innovative, and top economic free economies for 1995–2017. The study illustrates the channels through which economic reform affects innovation, and the study contributes to the innovation literature by examining additional determinants of technological progress different from existing studies (Brown et al., 2017; Kogan et al., 2017; Wen et al., 2021), among others. The empirical findings guide policymakers across countries with the distribution of trademark and patent applications. Therefore, by employing Blundell and Bond's (1998) GMM technique, we find a noteworthy and helpful impact of economic reform on technical innovation after controlling for other determinants of innovation, consistent with neoclassical and endogenous growth models prediction. The results are robust to different estimation techniques. This paper was also inspired by the index of economic freedom born as a data-driven policy guide that empirically evaluates countries' economic policies through a transparent and straightforward methodology. The following research works have also used this index of economic freedom, and their findings can be seen in the review of literature and hypothesis developments (Abdul Ghafoor Awan, 2020; Azid & Mahmood, 2009; Cole, 2005; de Haan & Sturm, 2000; Hafer, 2013a; Heckelman, 2000; Jia & Zhou, 2017; Roychoudhury & Lawson, 2010).

This paper is systematised as follows: Section 1 provides the introductory portion of the article. Section 2 deals with the theoretical literature, scientific literature, and hypothesis development of economic reform and technological innovation. Section 4 covers the approach taken, the specification of the model, and the data issues. Finally, Segment 5 outlines the observations and their explanation, and Segment 6 provides conclusions and recommendations.

2. Analysis of the theoretical literature, related scientific literature, and formulation of hypotheses

In line with Schumpeter (2017), technological progress theory notes that innovation necessitates the preparation and introduction of a consumer product in the capacity that will bring to fulfilment a consumer's unparalleled combination of factor(s). Diverse schools of thought have shaped the latest scholarly discourse on technical advancements. First, the 'neoclassical school of thought' illustrates the growth of capital, labour, and technical progress that changes with time and is based upon evolution. One of the neoclassical school advances is to see technology as an 'endogenous component of economic growth' and to see it as the same engine of growth as 'capital and labour.' Nevertheless, the 'neoclassical school' finds the process of creativity to be a black box and does not care for the knowledge of the inner workings of this black box. The neo-Schumpeterian school has come forth to correct this restriction. This school of thought refers to scientific advancement and examines the black box internal operating system. At first, the neo-Schumpeterian school developed a theoretical basis for technical progress through thorough empirical study and experimentation but did not provide more profound theoretical values. Therefore, in observing

the contributions of the schools of thought mentioned above, we imply that economic reform promotes innovation output through government efficiency, financial development, and the degree of democracy. Rogers and Adhikarya (1979) stated the considerations that would determine whether or not and at what rate the representatives of a given society would accept an idea or an invention. As proposed by Rogers, diffusion is a process by which creativity is transmitted across several networks over a particular moment between social structures. Four variables affect the transmission of ideas: imagination, advertising, time, and the social system. Roger claimed that the mechanism of invention diffusion had to be centred on human capital and that invention had to be globally accepted to support itself. However, Christensen et al. (2018) described disruptive innovation as technologies that help raise new markets and value networks over time, adding to early technology replacement. These advances improve goods and services in ways the consumer does not expect. We extend these theoretical models and contribute to the literature by empirically linking economic reform and innovation.

Although it is generally acknowledged in academic and practitioner literature that economic reforms are vital to long-term development, the causation of these elements is still under-researched *via* rigorous empirical study. There are different explanations for why economic reform is essential to technological innovation. Economic reforms can increase the effective structured financial and investment reform, boost foreign market competitiveness and growing exports and productive import replacements conducive to technological advancement, and directly affect production efficiency in a country. Aoki et al. (2017) emphasised structural reforms, innovations, and economic development by constructing a growth model distanced from the world's technology boundary. They summarised that businesses' creative opportunities and government decisions on reforms would strengthen each other through the combined effort of the public and private sectors. Otherwise, the economy will slide into an autonomous destructive trap where business innovation ceases to develop, and the government strives to enforce the economic policy. Garrett and Rhine (2011) examined how economic freedom affects state employment growth in the United States, and prior theories of economic growth and development were expanded. They discovered that job growth rates were higher in states with higher economic freedom—defined as the protection of private property and the operation of private markets with little interference from the government. The biggest influence on job growth in US states comes from less restrictive labour market regulations at the state and federal levels (Garrett & Rhine, 2011). Doucouliagos and Ulubasoglu (2006) employed meta-analytic methods to examine the literature on the connection between economic freedom and economic growth and found a typically positive direct association between the two. They found that stimulating physical capital is another way economic freedom positively impacts economic growth. If economic freedom positively affects growth, it is imperative to find the impact of reform policies on technological innovations, as innovation is a determinant of the growth of nations.

Hussain and Haque (2016), using the use of the 'Heritage Foundation's' created economic freedom index datasets, examined several unconventional predictors of economic development, which is an aggregate index created by combining many

sub-indices ('trade freedom index, financial freedom, labour freedom, business, and fiscal freedom index'). They demonstrated how important institutional elements are to economic growth and discovered a favourable correlation between the GDP growth per capita indexed and that growth rate (Hussain & Haque, 2016). de Haan and Sturm (2000) analysed numerous economic freedom measures and found that higher economic freedom promotes economic growth. Hall and Lawson (2014) studied economic independence, which corresponded to 'positive' consequences such as quicker growth, higher living standards, greater happiness, and so forth. Less than 4% of their sample perceived economic freedom as related to a 'negative' consequence such as rising income disparity. The evidence is unequivocal that economic independence is associated with a wide range of beneficial outcomes with nearly no negative costs (Hall & Lawson, 2014). Abdul Ghafoor Awan (2020) showed the importance of focusing on economic freedom as a vital element of economic progress. Heckelman (2000) tests showed that many of the particular underlying elements of freedom and the overall amount of freedom in a country come before development. However, two of the indices and growth are not shown to be related (Trade Policy and Taxation) (Heckelman, 2000). To promote innovation, Griffith et al. (2010) explored product market reforms with empirical evidence of improved innovation strength and efficiency in the manufacturing sector owing to the reforms introduced under the EU Single Market Programme and greater competition in the commodity market. Their research exploited exogenous variations in the Single Market Strategy's expected effects across countries and sectors to describe the impacts of reforms on average profitability and the outcome of profitability on innovation and product development. Domestic financial and trade reforms are directly connected to economic development in middle-income countries (Christiansen et al., 2013). From 26 transformational economies, reforms have been seen to play a crucial role in the revitalisation of growth in the economy (Eicher & Schreiber, 2010; Havrylyshyn & van Rooden, 2003; Melo et al., 2009). Many authors have positive outcomes, especially in developed countries (Jalilian et al., 2007; Nicoletti & Scarpetta, 2003). Therefore, government policies are expected to benefit innovation (Dutz et al., 2000). Moreover, many reforms are stimulated by technical advances that have altered the economic sectors' dynamics, projecting reforms as an excellent catalyst to further innovation.

However, the European economy has experienced significant upheavals in the previous 30 years, spurred by the expansion of ICT, intense innovation, and financial industry reforms to support creative entrepreneurship (Pradhan et al., 2020a). Thus, the study's findings give important insights into the measures contributing to Europe's long-term economic growth. To enhance the region's worldwide competitiveness, enterprise and innovation strategy should be the main drivers for the necessary economic growth (Pradhan et al., 2020b). Countries should thus use policies that promote innovation and encourage entrepreneurship to build their growth strategy (Pradhan et al., 2020b). Efficient and transparent financial process reforms to the financial system would help companies make up-to-date financial choices to minimise and be able to manage risks and reduce asymmetrical information and risk, enhancing ground-breaking initiatives between enterprises and financial establishments (Pradhan et al., 2019a). Third, strengthening the national innovation ecosystem,

according to Pradhan et al. (2019b), entails implementing the following reforms: providing appropriate financial and fiscal support for fundamental and translational R&D, new companies, patent application and trademark development, and the formation of a dynamic risk capital market; establishing a comprehensive regulatory framework and institutions; and improving the provision of scientific, technological and engineering maths-related (STEM) talent, including generous scholarship and other support for enrolment into STEM-related undergraduates.

Expanding reform removes impediments to long-term economic advancement, lets the market play a significant role in resource allocation, enhances governance, provides a favourable growth atmosphere, and unlocks the full productivity potential of workers (Pederson, 2004). Therefore, economic reform boosts ground-breaking development and encourages faster collaboration (Zhuang et al., 2011). In addition, innovation may be supported by ongoing reform and upgrading of the legislative and institutional framework of creative activities (Caiazza, 2016). Therefore, economic reforms are required to make public policy and regulatory frameworks more innovative in various policy areas, ranging from the general corporate environment—mainly in the services sector and web industries—to global investment and trade, financial industry, job markets, and training. Public ventures in science and fundamental research may showcase a vital role in creating ICT and other technology for general purposes and allowing for future innovation (Mazzucato, 2011). This underlies the necessity of changing public investment management and funding in science and research, and supporting public innovation in private-sector activities. This requires a suitable mixture of direct and indirect tools such as tax loans, direct support, and well-designed private–public partnerships, promotion of creative clusters, and a comprehensive appraisal of this public support. Financial market reform may also stimulate innovation and growth, especially by helping to decrease the funding shortages facing creative small businesses. The research shows that the most reliant sectors of industry are increasing rapidly in nations with more established financial institutions (Fowowe, 2017; Kroszner et al., 2007; Levine, 2003). Therefore, the sectors mostly spend on R&D that depends on external funding sources. Reforming the governance and financing of university education and scientific institutes by focusing on excellence and relevance can enhance public investment's contribution to scientific advancement and innovation (Cervantes, 2017). For example, the increase in funding for research is relevant to social and economic needs and establishing interdisciplinary research centres or networks that concentrate knowledge in certain areas of science and technology and stimulate study at the junction of several fields.

Moreover, as indicated in Figure 1 of the World Economic Index as of 2020, the world has activated reforms in specific sectors. The index scores reflect the better economic output of policy changes, creating higher economic dynamics in the private sector, strengthening the rule of law, encouraging productivity, restricting government administrative intrusiveness through democracy, and creating an environment for enabling innovations that solve people's economic and social problems. However, it is not the only financial achievement that economic independence is concerned with. The socio-economic gains of economic freedom go far more profound than higher

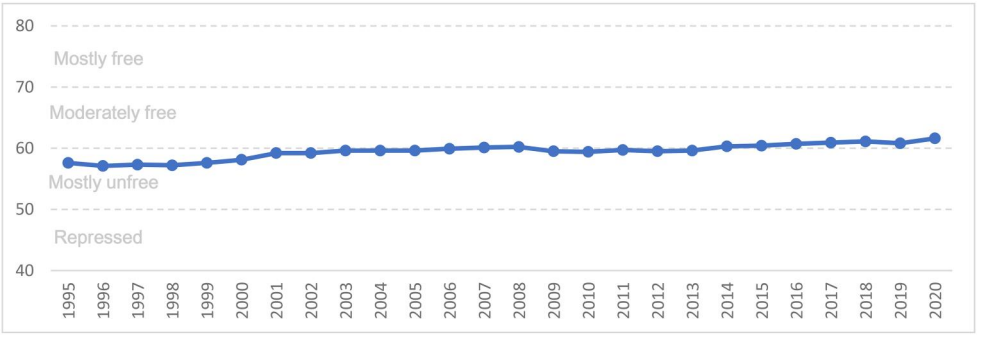

Figure 1. Trend analysis of the world economic freedom index. Source: author's computation.

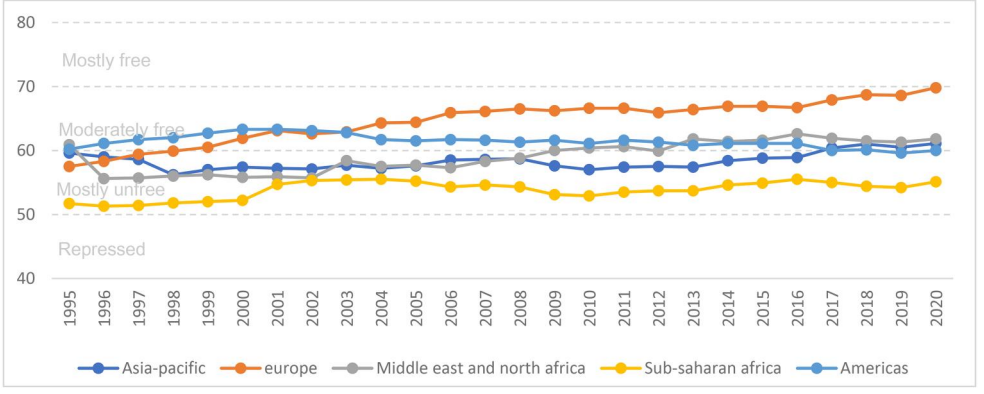

Figure 2. Trend analysis of the world economic freedom index according to regions. Source: author's computation.

wages or poverty reduction. People live longer, have decent health, and are better stewards of the environment in free economies. In Figure 2, Sub-Saharan Africa remained mostly unfree and needed more economic space for reformation among other regions. The European economy has the highest levels, usually with an overall rating of 68.6, far higher than the average of 60.8. Economic independence in the Middle East, North Africa, Asia-Pacific, and the Americas is near the global average of 61.3, 60.6, and 59.6, respectively, with sub-Saharan Africa getting a significant deficit of just 54.2.

Hypothesis 1: There is a significant positive relationship between economic reform and technological innovation.

One of the key elements influencing financial development and progress is economic freedom. There is a good reason to investigate how economic reform affects innovation. Rekha et al. (2021) revealed that the intersection of ICT dissemination, economic freedom, and financial development has a beneficial influence on financial inclusion in the long run, emphasising the significance of establishing a favourable

economic climate for sustained economic growth. Therefore, financial inclusion as one of the determinants of innovation paves the way for studying worldwide economic reforms on innovation performance. Financial development increases and determines technological innovation performance through reform policies that give way to financial freedom, investment freedom, etc. Hafer (2013) examined the 'link between economic freedom and financial development' and discovered that, on average, countries with greater initial levels of economic freedom display higher levels of financial intermediary development. There is an indication that more economic freedom is connected with enhancements in credit allocation at the micro level (Crabb, 2008; Hartarska & Nadolnyak, 2007; Michael et al., 2010) and better sovereign credit ratings (Roychoudhury & Lawson, 2010). Therefore, innovation output can be facilitated by improving government effectiveness and economic reform policies. Economic reform policies facilitate innovation through financial sector development in a bid for greater innovation output. Financial development, policymakers believe, boosts competitiveness to promote efficiency. Financial intermediaries (Schumpeter, 1911) are essential for innovation and growth.

Jia and Zhou (2017) 'investigated the effects of economic freedom (marketisation) on governance efficiency' and discovered that government effectiveness and economic freedom are positively connected. The 'factors market' is the most important sector for governance efficiency measures in terms of liberalisation and marketisation advancement (Jia & Zhou, 2017). If economic policies from the economic freedom index correlate positively with governance efficiency, innovation outcomes should be possible, as government efficiency is a determinant of technological innovation (Wen et al., 2021). Therefore, the government is a channel mechanism to reform policies and technological innovation performance. When there is greater economic freedom, the government operates more effectively. Furthermore, marketisation reform on economic institutions may undoubtedly impact political institutions (Jia & Zhou, 2017). The effectiveness of the government measures production efficiency and how effectively the strategy meets the intended goals (Kim & Voorhees, 2011; Weiss et al., 1995). Strong governance with well-structured financial development is concerned with appropriately providing citizens with sound economic and development strategies. Economic freedom fuels other forms of freedom in economic activities. It is not easy to envision how political or civil freedoms may be properly practised when individual autonomy, free trade of goods and services, and the protection of private property are not guaranteed (Vásquez, 2005). Economic freedom has risen in tandem with political and civil liberties worldwide, opening their markets to public and private investment, which has aided innovative growth. Economic freedom's fundamental position in democracy may be a significant factor in advancing democracy, and a good level of economic freedom is required to preserve political freedom and allow nations to innovate. More specifically, democracies value individual liberties and privileges, establish reform mechanisms that promote science and technological advancement, and defend property rights. Democracy fosters trade and capital account liberalisation (Milner & Mukherjee, 2009).

Hypothesis 2: Economic reform policies significantly and positively enforce technological innovativeness through government effectiveness, financial development, and democracy channels of mechanism.

There is little research on the link between economic reform policies and technological innovation. In actuality, economic reform policies may, directly and indirectly, affect innovation performance. This link between economic reform policies and technological innovation is vital for long-term economic prosperity.

3. Methodology, model specification, and data

3.1. Methodology

Panel data provide missed variables and additional dynamic statistics (Wooldridge, 2015). Panel data increase the sampling ability relative to 'time-series data', expected to produce more reliable outcomes. Therefore, we gather panel data from 1995 to 2017 to analyse the relationship between economic reform and technological innovation. The dependent variables (trademark and patent) and the explanatory variables (economic reforms, education, population, internet usage, income, investment, financial development, government effectiveness, trade openness, and democracy) are considered. Therefore, this analysis sets out the following panel data model:

$$\text{Innovation}_{i,t} = \alpha_0 + \alpha_1 \text{EconomicReform}_{i,t} + \beta \text{H}_{i,t} + \mu_i + \upsilon_i + \varepsilon_{i,t}, \qquad (1)$$

where innovation represents trademark and patent as the primary explained variables, H is a 'vector of explanatory variables' influencing technological innovation in one way or the other; μ_i and υ_i are the 'fixed effects for time and region', respectively; and $\varepsilon_{i,t}$ is the 'error term.' The traditional fixed-effect model provides a substantial range of stationary estimation procedures for benchmark estimation (Nickell, 1981). The GMM estimator (Arellano & Bond, 1991) deals with the endogenous issues in fixed results. The 'lag time value of the dependent variable' is used as an 'instrumental variable' in the estimation model to address endogeneity. The Sargan test will show and disclose variables with poor instruments in this methodology because the association between the lag instrument's variable and endogenous factors is low. Hence, a complex approach should be followed to assess economic reforms and innovation. The GMM calculation of the two-step method is seen as follows:

$$\text{Innovation}_{i,t} = \alpha_0 + \alpha_1 \text{Innovation}_{i,t-1} + \alpha_2 \text{EconomicReform}_{i,t} + \beta \text{H}_{i,t} + \varepsilon_{i,t}, \qquad (2)$$

where $\text{Innovation}_{i,t-1}$ signifies 'the lagged value' of the explained variable.

3.2. Variables selection

3.2.1. Dependent variables

Technological progress becomes a strong indicator of national innovation (Pradhan et al., 2020a; Wen et al., 2020; 2021). Therefore, we employ these as our dependent variables in the core regression. The details are as follows. (1) Trademark: The trademark has two essential purposes. First, the brand distinguishes explicitly between a

single undertaking's goods or services and those of another (WIPO, 2015). Second, trademarks contain some essential innovations not mirrored in conventional R&D and patent details, specifically non-technical innovations that attract great interest in service economies (Millot, 2009). We thus follow the relevant literature and include trademarks in our simple basic regression. (2) Patent: This is the aspirant's exclusive right to the design given by the state's endorsement authority during a certain time frame. Patent applications can be used as intermediary outputs to enhance technological innovation performance, since they incorporate resource input and efficiency (Hsu et al., 2014; Jalles, 2010).

3.2.2. Explanatory variables

3.2.2.1. Economic freedom index (economic reform). The 'economic freedom index' is built to help chart the development of economic reforms, prosperity, and prospects over two decades (Miller et al., 2019). This article's reform index is based on the quantitative reform indices (Cuervo-Cazurra & Dau, 2009; Kamal et al., 2018). The 'index of economic freedom' finds each aspect equally essential to achieve positive economic freedom benefits (Miller et al., 2019). A closer look at the economic reform shows a somewhat strong positive correlation with innovation output measured by *trademark and patent applications,* as indicated in Table 2. In this study's context, economic reforms permit more flexibility in the tracked economic indicators and are likely to promote growth and innovation. In turn, fostering more opportunities for people to develop their economies, eradicating poverty, and establishing sustainable prosperity depend heavily on growth and innovation. Some parts of economic reform concern a country's contacts with the rest of the world (for example, the degree to which an economy is accessible to global investment or commerce). On the other hand, most concentrate on policies within a country, judging people's freedom to utilise their labour or wealth without undue limitation or government involvement. Promoting and maintaining individual and societal innovation prosperity depends critically on these economic reform indicators. Similarly, suppression of economic freedom reform in one area (for instance, a disregard for property rights) may make it far more difficult to obtain high levels of freedom in other inclusive areas (Miller et al., 2019). Some of these economic reforms that can make or hamper innovation include economic freedom policies highlighted by the Heritage Foundation (Miller et al., 2019). In a market economy, the potential to amass private property and wealth is a major motivator for employees and investors. The impartial enforcement of contracts is a crucial component in the defence of property rights. Monetary independence necessitates a stable currency and market-determined pricing. A free and open investment environment provides maximum entrepreneurial possibilities and incentives for increased economic activity, higher productivity, and innovation.

3.2.3. Other explanatory variables

3.2.3.1. Education index (education). Higher education will help more people study and advance emerging technology (Bianchi & Giorcelli, 2020). Knowledge aggregation is also responsible for information flow and availability (Donou-Adonsou, 2019).

On the other hand, a higher level of human capital would aid the growth of technological advancement. *Population:* The total production factor is promoted under the theory of endogenous economic development (Ziller & Goodman, 2020). The optimised method produces more innovative inspirations for increased population density (Dong et al., 2016). *Real GDP (income):* GDP typically represents the overall degree of economic growth. Technical progress requires a well-anticipated socio-economic environment of overall economic development (Luo & Cheng, 2013). *Total export–import volume divided by GDP (trade):* Trade openness has a number of advantages, including increased key knowledge transfers, talent transfer, improved population, economic efficiency, and growth. Engaging in a global economic transaction is a way to increase business innovation, as trade access is positively related to production markets (Dotta & Munyo, 2019). *Total investment:* The investment contributes to capital stocks, and a major driving factor for output is the amount of capital available to an economy. If investments are successful, the efficiency of the economy could also improve. *Internet Usage:* The internet contributes to an encouraging and crucial role in economic growth to cross-country panel results (Choi & Hoon Yi, 2009; Choi & Yi, 2018). *Government effectiveness:* The government's performance could inspire innovation performance and impact innovation policy appraisal (Wen et al., 2021). *Financial development index:* The primary roles of a financial system are to monitor investment and corporate management after financial provision to promote commerce, diversification, and risk administration. In addition, it stimulates economic development by accumulating capital and technological advancement through increased savings, mobilisation and pooling of assets, the output of investment knowledge, promotion and support for foreign investment inflows, and optimisation of capital allocation. *Democracy:* Democracy tends to pay particular attention to respect for individual liberties and protecting individual rights to create structures that promote scientific and technical advancement and defend intellectual property.

4. Estimation and discussion of results

4.1. Data and descriptive statistics

Table 1 describes the variables, data sources, and descriptive statistics employed in this investigation. As shown in Table 1, the average number of trademarks in our survey is 9.374 for all nations. The standard deviation in various sample countries is 1.271, smaller than the mean values. Furthermore, the mean and standard deviation for patents are 7.043 and 2.179, suggesting lower cross-country diversity as the formal value is comparatively small compared with the other value. By comparing the average trademark and patent values, we deduce that the average trademark is better than a patent application and that the latter works less than the previous application. Our finding indicates that economic reforms' mean, median, and standard deviations are 59.925, 41.550, and 14.600, respectively. A matrix of the relationship between all relevant variables used in the analysis is shown in Table 2.

Table 1. Variable's definition and descriptive statistics.

Variables	Definition	Source	Mean	Median	SD
Trademarks	'The total number of patents applied by country residents'	WIPO database 2019	9.374	10.298	1.271
Patents	'The total number of trademarks applied by country residents'	WIPO database 2019	7.043	7.038	2.179
Economic Reforms	'The economic freedom index ranges from 0 to 100)'	GEFR 2020	59.925	41.550	14.600
Internet Usage	Percentage of internet users (percentage of the population)	WDI 2017	32.095	49.120	29.761
Education	Education index (average values)	HDRO 2017	0.692	0.552	0 .147
Population	Population (millions)	Penn World Table (2019)	2.680	2.966	1.610
Fdindex	Financial development index	IMF 2017	0.400	1.000	0.235
GovtEffectiveness	'Government effectiveness (ranges from 0 to 100)'	WGI 2017	54.117	50.537	27.980
Investment	'Total investment (percentage of GDP)'	WDI (2019)—Tcdata360	23.832	31.268	6.392
Trade	'Sum of exports and imports in goods as share of GDP'	WDI 2017	81.653	41.850	170.733
Income	'Real GDP at constant 2011 national prices (million 2011 US$)'	Penn World Table (2019)	12.133	1.704	12.596
Democracy	Direct democracy (ranges from 0 to 1)	GsoD Indices (2019)	0.170	0.5	0.187

WIPO: World Intellectual Property Organisation; GEFR: Global Economic Freedom Report; WDI: World Development Indicator; IMF: International Monetary Fund; WGI: World Governance Indicator; GsoD: Global State of Democracy Indices.
Source: Author's computation.

4.2. Basic results

Technical advancement is a powerful predictor for evaluating national innovation (Hsu et al., 2014; Pradhan et al., 2020a; Roper and Hewitt-Dundas, 2015; Wen et al., 2020). First, the GMM panel framework findings are summarised in Table 3. Our model focuses on the effect of economic reform on innovation growth, among other metrics. The other models incorporate control variables to validate the connection. Overall, the empiric data indicate that the results pass the GMM test, and thus the findings affirm the soundness of the determination for the sample nations.

Panel A treats economic reform and other 'explanatory variables' as endogenous. Panel B treats economic reform and other 'explanatory variables' as predetermined. Countries with high innovation progress levels are assumed to have advanced innovation output in the succeeding years (Wen et al., 2018). The GMM technique produces a positive coefficient of economic reform at 0.376, 0.367, 0.213, and 0.049 in columns (1)–(4), panel A, significantly different from zero at the 1% level. This suggests that an increase in innovation output can come from increased diverse economic reform initiated by the state. In column (6), an upsurge in economic reform by one unit boosts patent applications by 0.073 percentage points in panel A. Panel B shows that an increase in economic reform promotes trademark applications at a 1% level of significance from columns (1)–(3) and raises patent in columns (4) at a 5% level of significance. Therefore, economic reform is essential in promoting innovation, consistent with Aoki et al. (2017). This finding also relates to the studies that found a

Table 2. Correlation coefficients.

	Trademark	Patent	R&D/E	InternetUsage	EconomicReforms	Education	Population	Income	Fdindex	Investment	GovtEffectiveness	Trade
Trademark	1											
Patent	0.688	1										
R&D/E	0.185	0.315	1									
InternetUsage	0.245	0.234	0.209	1								
EconomicReforms	0.291	0.224	0.041	0.291	1							
Education	0.086	0.124	0.292	0.525	−0.030	1						
Population	0.421	0.600	0.048	−0.123	0.133	−0.400	1					
Income	0.548	0.772	0.305	0.236	0.238	0.008	0.844	1				
Fdindex	0.400	0.538	0.541	0.490	0.294	0.377	0.191	0.595	1			
Investment	0.274	0.276	−0.024	0.146	0.323	−0.135	0.132	0.148	0.137	1		
GovtEffectiveness	0.143	0.139	0.092	0.509	0.290	0.241	−0.051	0.115	0.265	0.202	1	
Trade	−0.076	−0.177	0.021	0.272	0.209	0.226	−0.460	−0.329	0.041	0.258	0.238	1

Source: Authors' computation.

Table 3. SYS–GMM estimator for the impact of economic reforms on trademark and patent innovation.

	Trademark			Patent		
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: EconomicReforms Endogenous						
Lagged dependent variable	0.514***	0.555***	0.529***	0.419***	0.432***	0.422***
	(0.002)	(0.019)	(0.012)	(0.006)	(0.016)	(0.016)
EconomicReforms	0.376***	0.367***	0.213***	0.049***	0.0198	0.073*
	(0.010)	(0.028)	(0.059)	(0.017)	(0.055)	(0.049)
Education	1.258***	1.332***	0.899**	1.002**	1.336***	0.694*
	(0.269)	(0.242)	(0.437)	(0.482)	(0.264)	(0.526)
Population	0.183***	0.521***	0.493***	0.074	0.334**	0.308
	(0.050)	(0.105)	(0.200)	(0.205)	(0.175)	(0.279)
Income	0.321***	−0.064	−0.153	0.584**	0.416**	0.183
	(0.048)	(0.105)	(0.200)	(0.283)	(0.205)	(0.286)
Trade		0.104*	0.194**		0.306***	0.224*
		(0.060)	(0.085)		(0.099)	(0.139)
Investment		0.203***	0.232*		0.104	0.067
		(0.085)	(0.138)		(0.178)	(0.226)
InternetUsage		0.139***	0.108***		0.095***	0.066**
		(0.013)	(0.028)		(0.024)	(0.030)
GovtEffective			0.008			0.0497***
			(0.007)			(0.011)
Fdindex			1.207***			1.197*
			(0.403)			(0.692)
Constant	−1.834***	1.759**	2.049*	−2.852	−2.773*	−0.874
	(0.525)	(0.842)	(1.584)	(2.845)	(1.890)	(2.187)
Sargan Test p-value	0.96	0.98	0.99	0.78	0.83	0.95
Arellano–Bond test p-value	0.000	0.000	0.000	0.000	0.000	0.000
Panel B: EconomicReforms Predetermined						
Lagged dependent variable	0.520***	0.543***	0.525***	0.431***	0.430***	0.411***
	(0.002)	(0.006)	(0.011)	(0.010)	(0.010)	(0.024)
EconomicReforms	0.259***	0.265***	0.296***	0.085**	0.010	0.004
	(0.009)	(0.029)	(0.019)	(0.036)	(0.056)	(0.066)
Education	1.268***	1.380***	1.397***	0.634*	1.182***	1.185**
	(0.248)	(0.306)	(0.299)	(0.445)	(0.350)	(0.557)
Population	0.184***	0.634***	0.395*	0.111	0.352***	0.337
	(0.077)	(0.189)	(0.228)	(0.289)	(0.137)	(0.289)
Income	0.411***	−0.079	0.118	0.541*	0.487***	0.431*
	(0.057)	(0.172)	(0.222)	(0.380)	(0.184)	(0.264)
Trade		0.365***	0.224**		0.415***	0.318***
		(0.123)	(0.098)		(0.114)	(0.121)
Investment		0.111*	0.072		0.131*	0.309**
		(0.077)	(0.110)		(0.076)	(0.145)
InternetUsage		0.144***	0.097***		0.077***	0.089***
		(0.020)	(0.039)		(0.012)	(0.015)
GovtEffective			−0.009**			0.016*
			(0.004)			(0.009)
Fdindex			0.414			0.596
			(0.402)			(0.551)
Constant	−2.480***	1.271	−0.431	−2.903	−4.256**	−4.224**
	(0.554)	(1.098)	(1.512)	(3.740)	(2.124)	(1.980)
Sargan Test p-value	0.98	0.97	0.99	0.75	0.81	0.93
Arellano–Bond test p-value	0.000	0.000	0.000	0.000	0.000	0.000

The regressions are estimated with a GMM estimator using 79 economies from 1995 to 2017. Panel A treats economic reforms and other explanatory variables as endogenous. Panel B treats economic reforms and other explanatory variables as predetermined. Robust standard errors are reported in parentheses. The significance of * is 10% significance level; ** is 5% significance level; *** is 1% significance level.
Source: Author's computation.

positive relationship with economic growth (Abdul Ghafoor Awan, 2020; Azid & Mahmood, 2009; Jia & Zhou, 2017; Roychoudhury & Lawson, 2010). However, the promoting effect of trademark applications is more significant than the patent. Adding the dependent variable's lagged value as a dynamic panel model will be produced using this explanatory factor (Nickell, 1981).

Similarly, we progressively incorporated other explanatory variables into columns (1)–(6) in Table 3, and the result remained positive and significant. As shown in Table 3, the lagged dependent variable's approximate coefficient is positive and essential at the 1% level for both regression outputs, indicating that countries with a high current innovation level appear to encourage higher innovation output in the future and are similar to the findings of Wen et al. (2016). The variable *education* positively and significantly impacts panels A and B's technical innovations. This suggests that intellectual capital in education promotes research and development crucial for national innovation (Ayres et al., 2007; Zambon & Monciardini, 2015). We also discovered a strong positive influence of population on trademarks and patents, indicating that population increase is a critical driver of technical innovation. However, the acceleration of persons with more amazing creative capacity drives technical progress (Collins et al., 2013). Our data show that trade openness enhances innovation in both panels and impacts technical development *via* imports, foreign direct investment, and exports (Kiriyama, 2012). Internet use is a crucial determinant of innovation, as closely related to Xu et al. (2019). Our findings indicate the importance of government effectiveness (Wen et al., 2021) and that ineffective governments frequently harm international technology adoption. Finally, the findings reveal that financial development is strongly associated with innovation output (Meierrieks, 2014).

4.3. Robustness test

4.3.1. Panel quantile regression (PQR)

The instrumental variable PQR accounts for the dependent variable's endogeneity and current stages. Therefore, the quantile regression can address the endogeneity problem by specifying the dependent variable (e.g., trademark or patent) (Koenker & Bassett, 1978). The regressors are provided with their first lags from the above procedure:

$$X_{i,t} = \alpha + \beta_j(X_{i,t-1}) + \varepsilon_{i,t}. \tag{3}$$

Here, $X_{i,t}$ is a regressor element for the country i at time t where α is 'constant', $\varepsilon_{i,t}$ is the 'error term', and $X_{i,t-1}$ is the 'first lag for the regressor' for country i at time $t-1$. The fitted values are obtained and used as exogenous variables in the QR estimation process. The θth quantile estimation of technical innovations is obtained by answering the given optimisation:

$$\min_{\beta \epsilon R^k} \left[\sum_{i \epsilon \{i : y_i \geq x_i\beta\}} \theta |y_i - x_i\beta| + \sum_{i \epsilon \{i : y_i < x_i\beta\}} (1-\theta)|y_i - x_i\beta| \right] \text{ where } \theta \epsilon (0,1). \tag{4}$$

Whereas the OLS depends on lessening the RSS, the QR minimises absolute deviations from the weighted sum. The conditional quantile of technological innovation given the regressors is:

$$Q_y + (\theta/X_i) \;=\; X_i\beta_\theta, \tag{5}$$

For the respective θth quantile, a unique parameter slope is modelled and is comparable to the OLS anywhere $E(Y/X) \;=\; X_i'\beta$ with the parameters reachable at the mean. The explained variable is technological innovation (Y_i), whereas X_i comprises an intercept and the explanatory variables in the model. The OLS in the quantile regression method becomes a 2SLS because of instrumentation (Efobi et al., 2019).

Figure A1 and Figure A2 demonstrate the cumulative distribution function of innovation variables measured by *trademark* and *patent,* which exhibits a high skew with a normal distribution as indicated in Figure A3 and Figure A4. Table 4 shows the estimated effect of *economic reform* on the *trademark* (panel A) and *patent* (panel B). The results in column (1) using fixed effect indicate *economic reform* increases *trademarks* by 0.468 at a 1% level and *patents* by 0.118 percentage points. Thus, the overall quantile regression from columns (2)–(6) in Panel A and B has expected signs with trademark and patent.

4.4. Further analysis

4.4.1. Heterogeneity analysis

Chang and Lee (2011) underlined sightseeing the 'heterogeneity' of societal advancement in several nation-states through excruciating research into distinct features. This is because independent transparency and economic growth substantially influence innovation activities. As a result, we want to create multiple comparison analyses in politics, economics, and innovation. The sub-samples based on dissimilar evolution and features include OECD, non-OECD, European, and top innovative nations. The research findings are shown in Table 5. The conclusions of each sub-sample are compatible with the overall sample and that economic reform can significantly boost innovation productivity. The government is persuaded to take a wide-ranging look at innovation programmes and strategies to encourage more expertise to join the innovation team and concentrate on innovative activities that maximise innovation output.

4.4.2. Mechanisms

We further focus on how economic reforms affect innovation. Based on the above analysis, we also explore the possible channels by which economic reformation may move innovation performance forward, even though we cannot rule out the possibility of other mechanisms. We affirm the existence of these mechanisms empirically as follows.

(1) Government effectiveness:

If all other factors remain constant, the more successful a country's government is, the higher the standard of social security and suitable policy formulation (Sacks & Levi, 2010). We argue theoretically that the link between economic reforms and technological innovation operates through the channel effect of an efficient

Table 4. Robustness: IV Quantile regression for the impact of economic reform on innovation.

Variable	FE	Q (0.10)	Q (0.25)	Q (0.50)	Q (0.75)	Q (0.90)
Panel C: Trademarks	(1)	(2)	(3)	(4)	(5)	(6)
EconomicReform	0.468***	1.240***	1.258***	0.769*	0.080**	0.041*
	(0.079)	(0.184)	(0.126)	(0.412)	(0.040)	(0.028)
Constant	10.15***	−1.442	−0.873*	1.577	4.751***	4.344***
	(4.108)	(2.804)	(0.615)	(2.038)	(0.587)	(0.709)
Controls	Controls	Controls	Controls	Controls	Controls	Controls
Pseudo/R^2	0.318	0.352	0.356	0.412	0.476	0.508
Panel D: Patents	(1)	(2)	(3)	(4)	(5)	(6)
EconomicReform	0.118**	0.686***	0.502***	0.240*	0.042	0.027
	(0.060)	(0.237)	(0.102)	(0.158)	(0.069)	(0.067)
Constant	−1.900	−8.620***	−6.790***	−5.467***	−4.628***	−1.647*
	(3.130)	(2.234)	(1.329)	(0.756)	(0.747)	(0.949)
Controls	Controls	Controls	Controls	Controls	Controls	Controls
Pseudo/R^2	0.579	0.449	0.494	0.535	0.571	0.601

The regressions are estimated using panel fixed effect and panel quantile estimator for the sample of 79 economies for 1995–2017. Panel C provides estimated coefficients using trademark applications. Panel D provides estimated coefficients using patent applications.
Source: Author's computation.

Table 5. SYS–GMM estimates of the impact of economic reform on technological innovation (sub-sample).

	Trademark				Patent			
	OECD	Non-OECD	EU	TopInno	OECD	Non-OECD	EU	TopInno
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
L.dep.variable	0.482***	0.527***	0.573***	0.902***	0.606***	0.346***	0.540***	0.977***
	(0.028)	(0.023)	(0.022)	(0.033)	(0.025)	(0.024)	(0.023)	(0.010)
Reforms	0.239*	0.347***	0.401***	1.806**	0.234*	0.072*	0.056*	0.063
	(0.134)	(0.117)	(0.086)	(0.808)	(0.125)	(0.037)	(0.032)	(0.093)
Constant	13.75***	−3.679	2.975*	−1.553	7.713***	−10.63***	−1.257	1.182**
	(2.285)	(2.147)	(1.781)	(4.794)	(2.022)	(1.452)	(1.552)	(0.575)
Controls	Controls	Controls	Controls	Controls	Controls	Controls	Controls	Controls
Number of Observation	682	1012	924	308	682	1012	924	308

GMM results are listed for the sub-sample estimations of OECD and non-OECD countries, European countries, and top innovative countries. Robust standard errors are reported in parentheses.
Source: Author's computation.

government. Therefore, economic reform will ultimately reinforce productive and service sector governance to raise innovation performance. Table 6 provides the impact of economic reform on innovation through government effectiveness. From Table 6, with columns (1)–(3) exploring the interaction between economic reforms and government effectiveness, we can find that economic reform and government effectiveness substantially complement innovative activities by optimising government efficiency, which answers hypothesis 2.

(2) Financial development

Theoretically, we argue that the financial sector's growth motivates the connection between economic reforms and technical progress. Banks promote technological development by providing entrepreneurs with promising new opportunities, such as inventions and invention methods (Acemoglu & Robinson, 2006). Table 7 provides the impact of economic reform on innovation through financial development. Columns (1)–(4) explore the interaction between economic reform and financial

Table 6. Mechanism: the SYS–GMM estimates of economic reforms on innovation through government effectiveness.

	Endogenous		Predetermined	
Variables	Trademark (1)	Patent (2)	Trademark (3)	Patent (4)
Lagged dependent variable	0.532***	0.367***	0.538***	0.413***
	(0.008)	(0.025)	(0.009)	(0.018)
EconomicReforms	0.274***	0.169***	0.187***	0.019
	(0.048)	(0.061)	(0.033)	(0.063)
GovtEffective	2.264***	1.971***	2.584***	1.161***
	(0.283)	(0.500)	(0.399)	(0.380)
EconReforms*GovtEffective	0.048***	0.056*	0.069***	0.012
	(0.015)	(0.031)	(0.008)	(0.014)
Controls	Controls	Controls	Controls	Controls
Constant	−6.690***	−10.88***	−8.226***	−6.260***
	(1.812)	(3.904)	(1.767)	(1.903)
Sargan Test p-value	0.88	0.77	0.91	0.83
Arellano–Bond Test p-value	0.000	0.000	0.000	0.000

See Table 3.
Source: Author's computation.

Table 7. Mechanism: the SYS–GMM estimates economic reforms on innovation through financial development.

	Endogenous		Predetermined	
Variables	Trademark (1)	Patent (2)	Trademark (3)	Patent (4)
Lagged dependent variable	0.539***	0.394***	0.540***	0.436***
	(0.011)	(0.029)	(0.009)	(0.015)
EconomicReforms	0.215***	0.035	0.184***	0.013
	(0.050)	(0.077)	(0.055)	(0.062)
Fdindex	−0.600	−0.096	−0.943	−0.065
	(0.433)	(1.341)	(0.652)	(0.757)
EconReforms*Fdindex	0.296***	0.222*	0.289**	0.342***
	(0.100)	(0.143)	(0.147)	(0.094)
Controls	Controls	Controls	Controls	Controls
Constant	1.308	−1.980	−0.684	0.681
	(1.382)	(4.939)	(1.270)	(2.672)
Sargan Test p-value	0.87	0.79	0.91	0.81
Arellano–Bond test p-value	0.000	0.000	0.000	0.000

See Table 3.
Source: Author's computation.

development. We can deduce that economic reform and financial development have a significant and complementary impact on innovative activities by optimising financial institutions' workings, answering hypothesis 2.

(3) Democracy

According to Frey (2010), democracy's growth and progression can be considered a social development sequence. Therefore, democracy is linked to a higher accumulation of human resources, lower inequality, lower political volatility, and increased economic independence. The regression model is shown in Table 8, where columns (1)–(4) explore the interaction between economic reform and democracy. Economic reforms reinforce the effect of democracy on innovation output in columns 1, 2, and 4.

Table 8. Mechanism: the SYS–GMM estimates of economic reforms on innovation through democracy.

	Endogenous		Predetermined	
Variables	Trademark (1)	Patent (2)	Trademark (3)	Patent (4)
Lagged dependent variable	0.557***	0.531***	0.476***	0.449***
	(0.009)	(0.009)	(0.015)	(0.017)
EconomicReforms	0.591***	0.357***	−0.0571	0.821*
	(0.082)	(0.112)	(0.226)	(0.557)
Democracy	7.028***	3.640*	−3.000	−11.42**
	(2.092)	(2.502)	(3.156)	(5.588)
EconsReforms*Democracy	1.706***	0.636*	−0.787	3.263**
	(0.492)	(0.493)	(0.681)	(1.451)
Controls	Controls	Controls	Controls	Controls
Constant	0.365	−1.302	−4.044	−3.951
	(0.857)	(1.197)	(2.898)	(3.362)
Sargan Test p-value	0.85	0.77	0.89	0.81
Arellano–Bond test p-value	0.000	0.000	0.000	0.000

See Table 3.
Source: Author's computation.

From the above findings, it can be inferred that both the baseline regression and the robustness inspection results indicate a rise in innovation output by improving economic reform. And the test of the framework shows that reform will increase innovation performance by reinforcing government efficiency, financial growth, and democracy.

5. Conclusions with relevant policy recommendations

Economic reform enacts some growth indicators, and the surest road to growth and development remains economic independence by embracing innovative national activities. This study has added to the innovation literature by assessing economic reform and innovation output. The study employed the SYS–GMM and the instrumental variable PQR (which accounts for simultaneity/reverse causality) for 79 countries from 1995 to 2017. This study first contributes to the literature by investigating the nexus between economic reform and technical innovation output. Our empirical results support the following findings: economic reform through economic freedom significantly increases innovation performance measured by *trademark and patent* applications after controlling macroeconomic and financial variables. This effect is substantial and robust. The mechanisms for significant effects include government efficiency, more credit access, allocational productivity gains, and democracy that have contributed to technological innovation. Therefore, to advance the output of innovation in the upcoming, there is a need to enhance the development of the financial sector, improve government efficiency, and transform government functions to attract more innovative talents. The findings remained the same after employing a sub-sample analysis.

A valued reform policy and coherent project approval and execution could help entrepreneurs reform a straightforward operating framework. However, the rotation of political parties hampers or unnecessarily interferes with engineering efforts owing to policy uncertainty and political influence. Governments should develop and strengthen the digital matching mechanism between funds and research initiatives to achieve greater innovation. We propose that each nation's government implement appropriate country-specific and regional policies to handle technological progress and effectively promote

innovation in the region. Technical development in most developed countries is measured by the pace of adapting and effectively exploiting existing technologies. However, the various speeds can be clarified by a country's willingness to embrace an acceptable economic climate to boost investment—entry to finance, trade, and the institutions' efficiency. In addition, reduced anti-competitive product market rules will encourage company R&D and improve innovation incentives. Furthermore, a little constraint is essential to foreign direct investment to allow cross-border information flows. Stable macroeconomic conditions and low real interest rates boost innovation through a stable and cost-effective investment environment. Internal and external financial resources are also available. Expansion of public research, which can assist business-sector research, would necessitate measures to increase the supply of human resources. Fiscal incentives can be beneficial in increasing R&D, particularly when businesses confront budgetary limitations. Tax breaks for commercial R&D are frequently shown to be more effective than direct government funding in stimulating company R&D. This is because enough R&D assistance is targeted at achieving government objectives rather than promoting private R&D. Openness to international development, especially when local R&D investment and capacity are likewise high leads to increasing productivity growth. Finally, the government should enhance the Intellectual Patent Protection Act to control inadequate competitiveness and preserve a fair market climate.

This study also has certain research limitations that should be addressed in future studies. First, economic reforms and firm-level innovation need to be studied. Second, this article did not dig into more segmented sections of economic reforms. For example, have financial reform, privatisation, security markets, property rights, and investment reform fostered technical innovation? How will these reforms affect innovations in developing countries? Second, it is also essential to research the effects of these economic reforms on green energy innovation in various nations. Third, the study samples in this paper are conducted globally; we anticipate that other nations and continents might be examined in the future. Finally, research can also be undertaken on computing the socio-economic effects of economic reforms on technological innovation and green innovation.

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Author contributions

JW: visualisation, Investigation, Supervision, Funding acquisition. CVO: conceptualisation, data curation, software, formal analysis, investigation, methodology, writing—original draft, writing—review & editing, resources.

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Appendix

Table A1. List of countries.

Country	Country	Country
Albania	Greece	Pakistan
Argentina	Guatemala	Peru
Armenia	Hungary	Philippines
Australia	Iceland	Poland
Austria	India	Portugal
Azerbaijan	Indonesia	Romania
Bangladesh	Ireland	Russian Federation
Belarus	Israel	Serbia
Belgium	Italy	Slovakia Republic
Bosnia and Herzegovina	Japan	Slovenia
Brazil	Jordan	South Africa
Bulgaria	Kazakhstan	Spain
Canada	Kenya	Sri Lanka
Chile	Kyrgyzstan	Sweden
China	Latvia	Switzerland
Colombia	Lithuania	Tajikistan
Croatia	Madagascar	Thailand
Cyprus	Malaysia	Tunisia
Czech Republic	Malta	Turkey
Denmark	Mexico	Turkmenistan
Ecuador	Moldova	Ukraine
Egypt	Mongolia	United Kingdom
Estonia	Montenegro	Uruguay
Finland	Morocco	Uzbekistan
France	Mozambique	Zambia
Georgia	North Macedonia	
Germany	Norway	

Source: Author's computation.

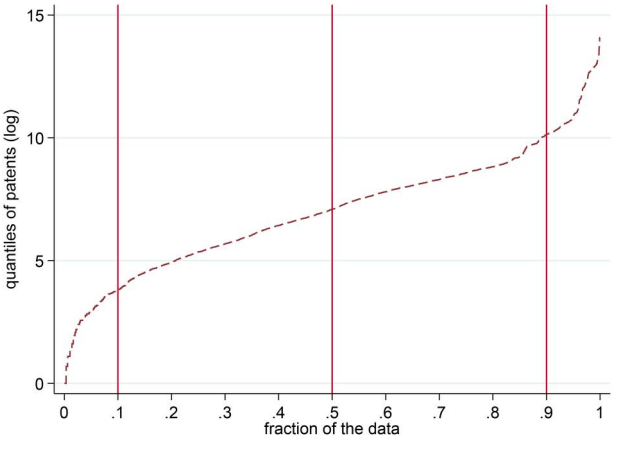

Figure A1. Quantiles of patent applications.
Source: Author's computation.

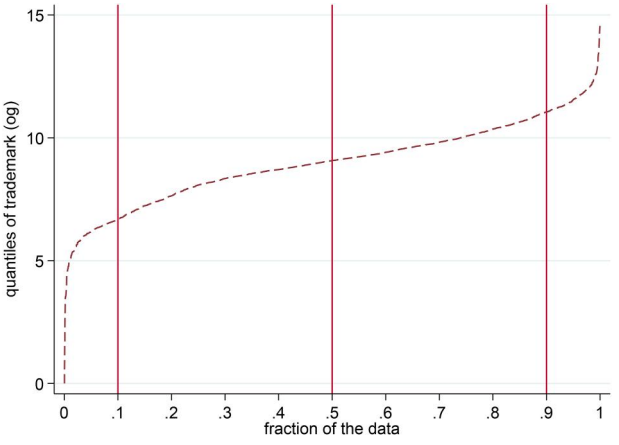

Figure A2. Quantiles of trademark applications.
Source: Author's computation.

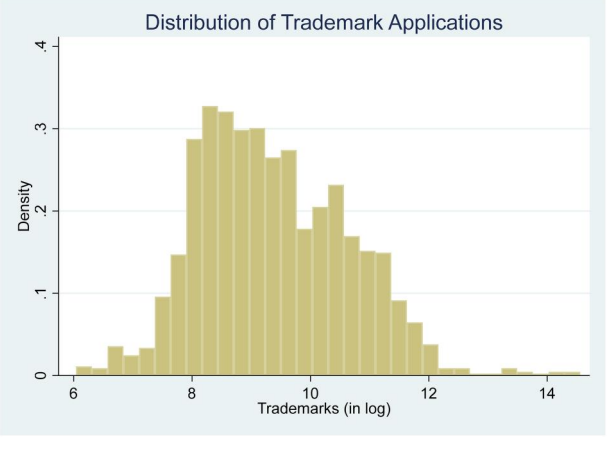

Figure A3. Distribution of trademark applications.
Source: Author's computation.

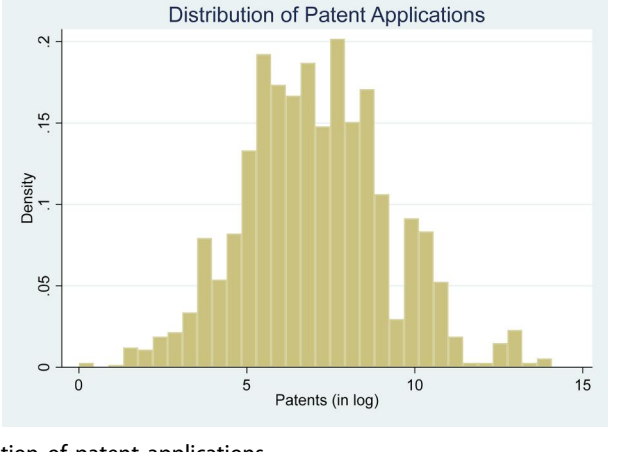

Figure A4. Distribution of patent applications.
Source: Author's computation.