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The Relationship Between Intellectual Property Rights, Innovation, and Economic Development in the G20 and Selected Developing Countries

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Abstract
The main objective of this study is to examine the relationship between intellectual property right, economic growth, research and development, trademark, and government effectiveness in the G20 and developing countries. The study applied econometric approaches such as panel vector autoregression (PVAR), PVAR Granger causality, variance decomposition, and impulse response functions (IRF). We also applied heterogeneous and second-generation panel data approaches that are effervescent to slope heterogeneity and cross-sectional dependency to panel data revolving 20 countries (G20) and 27 developing countries from 2004 to 2022. To summarize the findings of this research, (1) the study discovered that economic growth, research and development, trademark, and government effectiveness have positive and significant effect on intellectual property right in the G20 countries. (2) Economic growth, trademark, and government effectiveness have positive and significant influence on intellectual property right, but research and development has no relationship with intellectual property right in the developing countries. (3) In the G20 countries, IPR responds favorably to economic growth, research and development, trademark, and government effectiveness shocks. (4) Lastly, IPR responds favorably to economic growth, trademark, and government effectiveness shocks in the developing countries. Our findings highlight the critical role that innovation-growth policies and economic development play as the primary global drivers of intellectual property rights.

Keywords Intellectual property right · Research and development · Economic growth · Trademark · Government effectiveness

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Introduction

Globalization has become a critical issue, and intellectual property (IP) is an integral and essential part of this globalization, especially since the world is moving towards a knowledge economy. How intellectual property is managed and accessed determines its efficiency in this new knowledge economy and who uses it (Coelli et al., 2022; De Rassenfosse et al., 2022; Ilie, 2014). It is generally accepted to be essential for promoting innovation and accelerating economic growth (De Rassenfosse et al., 2022; Neves et al., 2021). Over the years, many intellectual property rights (IPR) tools with different aims and fields for applications have been established to protect one's intellectual creations (Ilie, 2014). The importance of IPR for economic activity relies on innovation. Among the several drivers of economic growth, innovation has garnered the greatest attention. The World Trade Organization has acknowledged the value of innovation in fostering economic development. WTO has emphasized the essential role of IPR in gaining innovation globally but varies from country to country and depends on the number of resources that a country apportions for the promoting intellectual assets (Correa, 2020; Hudson & Minea, 2013). This has encouraged and strengthened investment in innovative activities which has promoted economic development. This is because innovation grants successful inventors to have a brief monopoly over their creations. How or how much IPR stimulates innovation and economic growth has attracted considerable attention from researchers (Bruno et al., 2021; Zheng et al., 2020).

Scholars and policymakers have paid close attention to intellectual property rights (IPR) and their macroeconomic implications in recent decades. In spite of a large body of theoretical and empirical research, there is conflicting information about how intellectual property rights (IPRs) affect innovation and economic expansion. IPR's ability to spur innovation and, consequently, economic growth has been questioned by certain academics (Baker et al., 2017; Neves et al., 2021). Furthermore, even though it has been disregarded or minimized in economic theories pertaining to economic growth and development, intellectual property protection is seen as a component of economic policy (Ilie, 2014).

In an era marked by significant economic growth worldwide, a fundamental discord prevails, particularly between developed and developing nations, about the implementation of robust IPR regimes. This schism comes to the fore in the debates surrounding competition laws and the potential monopolistic tendencies inherent in IP laws, an issue that continues to vex the intellectual discourse in developing countries. A substantial hurdle arises from the fact that these nations exhibit a wide spectrum of variation in their scientific and technical infrastructure, which casts doubt on the universal applicability of IP. While the notion of a global uniform IP standard may seem simple, it necessitates careful consideration of numerous micro and macro factors (Laik, 2005; Neves et al., 2021; Viglioni et al., 2023).

Furthermore, the role of economic development in intellectual property remains a contentious subject, with differing viewpoints (Bannerman, 2020; Baker et al., 2017; Henry & Stiglitz, 2010). Complicating matters, the IP of the WTO do not always align with the needs of developing countries; they often

serve corporate interests in developed nations. For example, the extension of patent protection to global pharmaceutical companies, which may come at the expense of the healthcare of impoverished populations, or the prolonging of copyright for books beyond the time required to compensate authors, thereby limiting access to educational materials in developing nations, creates tensions and uncertainties. These intricacies of intellectual property rights, particularly within the framework of the Trade-Related Aspects of Intellectual Property Rights (TRIPS) Agreement, suggest that IPR serves multifaceted developmental objectives (Baker et al., 2017; De Rassenfosse et al., 2022).

However, our research endeavors to bridge an existing literature gap by providing a comprehensive comparative analysis of the diverse IPR regimes in G20 countries and selected developing nations. This analysis considers variations in IPR enforcement, protection levels, and their implications on innovation and economic growth. While previous research focuses on aggregate effects, a notable research gap lies in the examination of sector-specific variations. Different industries may exhibit varying degrees of susceptibility to the influence of IPR regimes. For instance, the impact of IPR on pharmaceutical innovation may significantly differ from its impact on technology or entertainment sectors. Investigating these sectoral nuance is of paramount. Furthermore, although international agreements such as TRIPS play a significant role in shaping IPR policies, the specific mechanisms and impacts of these agreements on innovation and economic development in G20 and developing countries have remained unexplored. Understanding the intricate interactions between domestic IPR regulations and international agreements is essential for a comprehensive analysis (Coelli et al., 2022; Ranjan, 2022).

The contribution of this study stows in its comprehensive exploration of the intricate relationship between intellectual property rights (IPR), innovation, and economic growth. It delves into the multifaceted nature of this nexus, bridging existing research gaps and addressing conflicting findings. While much of the prevailing research has asserted that stringent IPR protection fosters innovation and fuels economic growth, our study recognizes an alternate perspective, exemplified by Neves et al. (2021), which suggests that reducing IPR protection might stimulate innovation and enhance economic growth. This dichotomy in views, both in theoretical foundations and empirical evidence, has created a complex web of interpretations, as elucidated by Viglioni et al. (2023) and Cho et al. (2015). The complexity of these relationships is compounded by the diversity observed across G20 and some selected developing countries, stemming from the myriad methodological approaches employed (PVAR, Impulse response function, granger causality and variance decomposition). For instance, Hammami (2021) and Yu (2016) highlights the pivotal role of IPR in driving R&D activities in developed economies, but the impact in developing nations varies significantly. Chen and Puttitanun (2005) reveal positive associations between IPR and innovation in developing countries, accompanied by a U-shaped relationship between IPR and economic growth. Gervais (2014) suggests that heightened IPR protection can expedite economic growth in developed countries and may also have a positive influence on the growth rates of these economies.

Considering the complexities of the big question "do innovation and economic growth influence intellectual property rights (IPRS) in the G20 and the developing countries?" Therefore, the main objective of this study is to examine the relationship between IPR, innovation, and economic growth in the G20 and developing countries. To address the above-stated question, this research seeks to, firstly, unravel how variations in the rate and nature of R&D and trademark across G20 and selected developing countries influence intellectual property rights (IPR); secondly, delve into how the causal relationships between innovation, economic development, and IPR differ among G20 and developing countries; and lastly, explore the extent to which government effectiveness affects IPR in the G20 and selected developing countries.

The structure of the paper is as follows: A concise summary of the research on the connection between IPR, innovation, and economic growth is given in the "Theoretical Literature" section. The methodologies used for the study are presented in the "Data and Methodology" section. The results and analysis are reported in the "Result and Discussions" section, and the "Conclusion and Policy Implications" section concludes it.

Theoretical Literature

This paper is firmly anchored in four distinct theoretical literature strands that collectively constitute the theoretical bedrock for comprehending the intricate dynamics governing the relationship between intellectual property rights (IPR), innovation, and economic development. These foundational theoretical perspectives not only serve to elucidate the multifaceted interactions within individual national contexts but also provide insights into the broader global landscape. By weaving together insights from these four distinct strands of theoretical literature, the study seeks to illuminate the complex connections that exist between IPR, innovation, and the advancement of economies.

Endogenous Growth Theory

Endogenous growth theory, pioneered by economists like Paul Romer, highlights the importance of knowledge and innovation as the main forces behind economic development. According to this theory, economic growth is not solely a result of factors like capital and labor but is also determined by the accumulation of knowledge and technological progress. IPR plays a pivotal role in this framework as they provide incentives for firms and individuals to invest in research and development (R&D). Protection of intellectual property, such as patents and copyrights, grants innovators exclusive rights to their creations, encouraging them to pursue innovative activities (Gómez-Caicedo et al., 2022; Arjun et al., 2020; Romer, 1990). Romer's model of endogenous technological change posits that an increase in the level of protection for intellectual property leads to more significant investments in R&D, which, in turn, fuels economic growth (De Rassenfosse et al., 2022). In developing countries,

this theory suggests that strengthening IPR regimes can foster innovation, spur technological progress, and drive economic development (Gómez-Caicedo et al., 2022; Arjun et al., 2020; Romer, 1990).

Joseph Schumpeter's theory of economic development is closely related to innovation. Schumpeter argued that innovation is a disruptive force that leads to "creative destruction." This process involves the replacement of old technologies and business models with new, more efficient ones, driving economic progress. Intellectual property rights can be seen as facilitating this innovation-driven economic development. They offer innovators a period of market exclusivity to recoup their investment and reap profits, which further encourages entrepreneurs to engage in innovation (Gómez-Caicedo et al., 2022; Schumpeter, 1942).

Utilitarian vs. Natural Rights Theories

The debate over the philosophical underpinnings of intellectual property rights revolves around the tension between utilitarian and natural rights theories. The utilitarian perspective views IPR as promoting innovation for the greater good of society. In contrast, the natural rights theory posits that individuals have a fundamental moral claim to the products of their intellectual labor. The balance between these two perspectives varies across different countries and regions, influencing the design and implementation of intellectual property laws (Braybrooke, 2003; Drahos, 2016).

Trade-Related Aspects of Intellectual Property Rights (TRIPS)

The World Trade Organization's TRIPS Agreement seeks to harmonize intellectual property standards on a global scale. It establishes a framework for protecting intellectual property rights internationally. However, critics argue that this international framework often serves corporate interests in developed countries at the expense of developing nations. The TRIPS Agreement has faced challenges, particularly regarding access to essential goods like medicines and educational materials (Agreement, 1994; Correa, 2020; Ranjan, 2022). While TRIPS is based largely on earlier international IPR agreements, it contains some significant additions, such as the universal extension of patent terms to at least 20 years. TRIPS also provides clear guidelines about the effective and expeditious enforcement of IPRs a crucial element that was missing in earlier international agreements. The main objective of TRIPS is to introduce a measure of compulsion into the international arena, and in particular to improve IPR protection in developing countries, where in recent years most of the IPR infringing activities tended to occur. The dispute settlement provisions of TRIPS are part of the WTO enforcement measures agreed in the Uruguay Round negotiations (Correa, 2020).

Innovation Theories in Developing Countries

In developing countries, where innovation systems may differ significantly from those in advanced economies, understanding the dynamics of IPR, innovation, and

economic development is complex. Developing nations often lack the infrastructure, financing, and skilled human capital necessary for robust innovation systems. The relationship between IPR and innovation in these contexts is a subject of ongoing research (Hang & Chen, 2021; Johnson & Lundvall, 1992). Different industries may be affected in diverse ways by IPR regimes. For instance, the pharmaceutical industry strongly depends on patent protection to recoup substantial research costs, which can lead to higher drug prices. In contrast, technology or entertainment industries may experience different impacts from IPR protection. Understanding these sectoral variations is crucial for crafting effective IPR policies (Hang & Chen, 2021; Mansfield, 1998; Slimane & Ramadan, 2017).

The impact of IPR protection on innovation and economic growth in developing economies is not uniform. Some studies suggest that stronger IPR protection leads to more innovation, particularly in sectors like pharmaceuticals. Others argue that weaker IPR protection may encourage grassroots innovation and foster economic development. The complexity of these effects reflects the diversity of approaches and research findings in the field (Lema et al., 2021; Lerner, 2009; Maskus, 2000).

In summary, the theoretical literature on IPR, innovation, and economic development offers a rich tapestry of perspectives, from endogenous growth theories to Schumpeterian innovation theories, and from philosophical debates to the global implications of international agreements. Understanding these theories is essential for assessing the complex relationships between IPR, innovation, and economic development in diverse contexts.

Related Literature

According to the endogenous growth mode, innovation is done to profit from the introduction of new products. However, as human knowledge grows, the cost of innovation decreases since each new product adds to the body of knowledge accumulates. Innovation and economic growth are likely to increase when conditions are created that support the acquisition of human knowledge and intellectual property rights (Coelli et al., 2022). For instance:

Abdin et al. (2024) propose that due to resource constraints, firms in transition economies tend to follow an imitational innovation strategy, and therefore, from this perspective, IPR protection can be crucial for firm-level innovation within those economies. Using data from the World Bank Enterprise Survey (WBES) consisting of information for about 21,960 firms from 27 Eastern European and Central Asian transition countries and employing a two-step probit model with endogenous regressors, they find that adverse effects of FC and IPR on firms' innovation activities are driven from within as well as between industries. Focusing on the differential impacts of FC and IPR protection across industries, we direct potential causal pathways from easing FC and optimal IPR protection to encourage firms' innovation. Based on the findings, while very strict IPR protection is detrimental to firms' product and process innovation in industries with limited resource and skill capabilities, it is nevertheless helpful for research and development (R&D) activities in industries characterized by strong R&D and IP capacities.

Zheng et al. (2023) apply a triple difference (DDD) method to estimate the effect of IP on corporate digital innovation using the patent data of Chinese A-share listed companies from 2009 to 2020 and the pilot of China's intellectual property (IP) courts in late 2014. Their findings suggest that protection of IP has a positive impact on innovation and that it contributes more to underlying digital technology innovation. Moreover, small firms are more likely to be affected by IP in their innovation activities than large firms.

Viglioni et al. (2023) examined how stronger IPRs affect economic growth and moderate innovation. Using a sample of 18 Latin American countries from 2007 to 2018, employing the Driscoll-Kraay robust standard errors, two-stage least squares (2SLS), and Generalized Method of Moments (GMM). Results confirm an inverted U-shaped relationship between IPRs and economic growth. Hence, the majority of Latin countries continue to vary in the factors of production that support robust IPRs. Conversely, robust IPRs effectively improve the relation between innovation and economic growth. In recent decades, intellectual property rights (IPR) and their macroeconomic effects have attracted considerable attention from both policymakers and academics. Despite a substantial theoretical and empirical literature, evidence regarding the impact of IPR protection on innovation and economic growth is mixed. In this paper, we conduct a literature review and meta-analysis of the topic, and find that IPR have an overall positive effect on innovation and growth. However, the effect on innovation is weaker in developing countries than developed countries (Neves et al., 2021).

Roh et al. (2021) examine the role of open innovation on green innovation divided into green process and green product innovation. The methodology was based on the partial least square structural equation method (PLS-SEM) with 1203 samples. The results revealed that a firm's intellectual property rights and government support significantly affect open innovation, green process innovation, and green product innovation while open innovation played a mediating role between each. This study proposes several implications emphasizing the mediating role of open innovation in enhancing green process innovation along with the direct and indirect effect of intellectual property rights and government support on green innovation. The sensitivity of this relationship to the degree of intellectual property rights (IPR) protection throughout the R&D subsidiaries of MNEs is investigated by Bruno et al. (2021). They contend that when an MNE bases its R&D operations in areas with stronger intellectual property rights, its innovative performance would improve. Furthermore, when considering the internal geography of MNEs' R&D operations, the distance between the IPR regimes innovation.

Hammami (2021) tested the impact of intellectual property protection reforms on the dynamic of technological progress within sampled developing countries. They argue that IPR's effect on innovation depends on the national absorptive capacity that is the capacity of the country to detect, analyze, and use the new technology. Using a panel data fixed effect (FE), instrumental variable (IV), and negative binomial models (NEGBIN), and controlling for heterogeneity between the countries, three important results emerge. Firstly, they found that IPRs are negatively correlated with innovations in the sample. Secondly, the absorptive capacity has a positive effect on technological progress. Thirdly, the deeper the

absorptive capacity is, the higher the expected negative effect of IPRs. They explained that their outcome by the fact that IPRs would increase the small and incremental cost of innovation and hinder the possibility of inventing around when the country has developed some basic technological capabilities; otherwise, the effect will be marginal.

The impact of protecting intellectual property rights (IPRs) on innovation in China during the period surrounding state-owned enterprise (SOE) privatizations was examined by Fang et al. (2017). They discovered that following SOE privatizations, innovation rises, and that this growth is greater in cities with robust IPR protection. Private sector companies are more sensitive to IPR protection than state-owned enterprises (SOEs), and IPR protection increases enterprises' incentives to innovate.

Kim et al. (2012) examined how the role of patents and utility models in innovation and economic growth varies by level of economic development. Using a panel dataset of over 70 countries, they found that patent protection is an important determinant of innovation and that patentable innovations contribute to economic growth in developed countries, but not in developing.

Janjua and Samad (2007) estimated the impact of IPRs protection on economic growth for a panel of ten middle-income developing countries, using pooled least square estimation techniques by applying both fixed and random effect models, and both unbalanced data from 1960 to 2005 and balanced data from 1970 to 2005. Both fixed and random effect models do not support the positive link between IPRs and economic growth. This suggests that although IPRs protection stimulates economic growth, yet these developing countries are at the transitional stage of their economic development and the cost of innovation is higher than the cost of imitation. This means that these middle-income developing economies are not well-prepared to accept this challenge at the present stage of economic and infrastructural development.

Gaps in the literature, the reviewed literature indicates that the implications of IPR are not entirely evident. The results almost always show that IPR has a direct and beneficial influence on innovation and growth. Nonetheless, it appears that the strength and direction of the effect vary per nation. Furthermore, notable variations in methodology exist between researches, which additionally aid in the explanation of the variability shown in the empirical results. First, disparities in data sets could result in disparate approximations of the impact of intellectual property rights (IPR) on innovation and growth. Furthermore, a significant flaw in the research is that most evaluations do not take into consideration a direct correlation between the various protection systems and the products, as noted by Moser (2013) and Hall et al. (2014). Second, the degree of IPR protection indices are measured by studies using various indicators. When analyzing the relationship between IPR, innovation, and growth, alternative measures should be considered in addition to the Ginarte-Park Index (GPI), which is the most used measure of IPR in the empirical literature. This is because the GPI does not capture all the dimensions of IPR.

Data and Methodology

Theoretical Rationale of the Variables

Prior to laying out the framework for using economic data to examine the relationship between intellectual property right, innovation, and economic growth in the G20 and developing countries, we offer a theoretical justification for choosing the study's variables. IPR, which is the dependent variable, is mostly measured by the payments and receipts between residents and nonresidents for the authorized use of proprietary rights. Some studies suggest that there is a positive and strong relationship between IPR, innovation, and economic development (Zheng et al., 2023)

GOE organized as perceptions of the quality of public services, the quality of the civil service and its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies play a role in accomplishing the goal (Kaufmann et al., 2011). Promoting IPR in economic activities context would necessitate effective government that will continually raise the bar for creating rules and regulations and implementing policies (Khan et al., 2023). Therefore, we chose GOE as one of the determinants of IPR.

Similar, R&D activities are considered as the input and IPR are the product (output) of technical innovation. According to this view, while R&D activities increase IPR by producing innovations, IPR also improve profitability by giving inventors a monopoly power and promoting R&D activities (Ma et al., 2022). This justifies the inclusion of R&D in our study.

GDPPC is selected for the study due to the fact that recent literature has indicate that economic growth is an effective policy instrument to overcome the intellectual property right issues, which not only ensures innovations but also promotes IPR (Neves et al., 2021). The process of IPR is strongly influenced by economic growth and stability of the country. Hence, it is difficult to conceive strong economic development without promoting IPR (Neves et al., 2021; Viglioni et al., 2023).

Furthermore, TMK measured by the resident and non-resident applications filed with the IP office by the first-named applicant. Literature has voiced TMK which is used as a proxy for innovation is connected with IPR (Krasnikov & Jayachandran, 2022; Castaldi et al., 2022), therefore the use of TMK in our study.

This research uses annual data from G20 and developing countries for each variable from 2004 to 2022. In all, 47 countries, which we break them into G20 and 27 developing countries, were included in this analysis. We measured IPR in terms of intellectual property rights (Current US dollars), R&D in terms of research and development investment (% of GDP), economic growth in terms of GDPPC (current US dollars), TMK in terms of trademarks (current US dollars), and GEF in the estimation of governance (ranges from −2.5 (weak) to 2.5 (strong) governance effectiveness) based on studies by Gyedu et al. (2021) and Bannerman (2020). The study sourced IPR, GDPPC, R&D, and TMK data from

the World Bank and GEF data from the Worldwide Governance Indicators database (through World Database Indicators and Worldwide Governance Indicators database, 2023). The study utilizes methods such as panel vector autoregression (PVAR), PVAR Granger causality, variance decomposition, and impulse response functions (IRF). As a normal practice in econometrics to minimized heteroscedasticity in the data (Ntarmah et al., 2021), we transformed the variables into their natural logs. Table 1 presents summary of the variables and data sources.

Model Estimation

We formulate an equation that captures the connection between intellectual property rights, innovation, and economic development in the context of G20 and selected developing countries.

$$IPR = f(GDPPC, R\&D, TMK, GEF) \tag{1}$$

IPR represents intellectual property rights. *GDPPC* stands for economic growth expressed as GDP per capita. *R&D* and *TMK* denote research and development and trademark respective, which are used as a proxy of innovation variables. *GEF* represents control variable known as government effectiveness.

We incorporate the natural logarithm of the variables in the econometric equation for intellectual property right:

$$\ln(IPR) = \alpha + \beta_1 \ln(GDPPC) + \beta_2 \ln(R\&D) + \beta_3 \ln(TMK) + \beta_4 \ln(GEF) + \varepsilon \tag{2}$$

ln(*IPR*) represents the natural logarithm of the level of intellectual property right. *ln*(*GDPPC*) represents the natural logarithm of GDP per capita. *ln*(*R* & *D*) represents the natural logarithm of research and development. *ln*(*TMK*) presents the natural logarithm trademark. *ln*(*GEF*) represents the natural logarithm of government effectiveness. α is the intercept. β_1 ,β_2 , β_3 , and β_4 are coefficients representing the relationships between the logged variables. ε represents the error term. Taking the natural logarithm of these variables is a common approach in econometrics to address issues like non-linearity and heteroscedasticity. It can also help in interpreting the results in terms of elasticities, which indicate the percentage change in the dependent variable associated with a 1% change in the independent variable.

Econometric Approach

Panel Vector Autoregression (PVAR)

This study employed panel vector autoregressive (VAR) model to estimate the results. The panel VAR was employed because it is one of the long panel data (long series) models useful for handling endogenous and exogenous shocks which is the most important source of macroeconomic dynamics. Also, it accounts for the dynamic heterogeneity in cross-sectional data by introducing fixed effects to improve consistency and coherence measurement (Ntarmah et al., 2021). Again, the model follows contemporary movements in series than following purely specific

Table 1 Summary of variables, data sources, and description

Variable	Description/index for measuring the variables	Source
Intellectual property right (IPR)	Payments and receipts between residents and nonresidents for the authorized use of proprietary rights (Current US dollars)	World Bank (2023)
Economic growth (GDPPC)	GDP per capita (constant 2010-USD)	World Bank (2023)
Research and development (R&D)	The ratio of total R&D expenditures to GDP (% of GDP)	World Bank (2023)
Trademark (TMK)	Resident and non-resident applications are filed with the IP office by the first-named applicant (% of GDP)	World Bank (2023)
Government effectiveness (GEF)	It is organized as perceptions of the quality of public services, the quality of the civil service and its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment (from −2.5 (weak) to 2.5 (strong)	Worldwide Governance Indicators (2023)

macroeconomic dynamic concepts (Kireyev, 2000). Thus, the model is neutral against specific growth-innovation theories and as such making it possible for combining theories in the estimation process. Moreover, the panel VAR model makes no difference between endogenous and exogenous variables in the model and treats all the variables as endogenous. This is consistent with the reality of interdependence, whereby each variable depends on its own historical realization and that of other variables. Finally, the panel VAR model through its impulse response function evaluates the effects of orthogonal shocks (changes) by describing the impact of shocks from one variable to another while retaining other variables that are invariant. According to Love and Zicchino (2006), the general formula for panel VAR can be represented as follows:

$$IPR_{it} = \alpha_{IPR} + \sum_{j-1}^{p} \beta_{1j} IPR_{i,t-j} + \sum_{j-0}^{q} \gamma_{1j} GDPPC_{i,t-j} + \sum_{j-0}^{r} \delta_{2j} R\&D_{i,t-j} + \varepsilon_{1it} \tag{3a}$$

$$GDPPC_{it} = \alpha_{GDPPC} + \sum_{j-1}^{p} \beta_{2j} GDPPC_{i,t-j} + \sum_{j-0}^{q} \gamma_{2j} IPR_{i,t-j} + \sum_{j-0}^{r} \delta_{2j} R\&D_{i,t-j} + \varepsilon_{1it} \tag{3b}$$

$$R\&D_{it} = \alpha_{R\&D} + \sum_{j-1}^{p} \beta_{3j} R\&D_{i,t-j} + \sum_{j-0}^{q} \gamma_{3j} GDPPC_{i,t-j} + \sum_{j-0}^{r} \delta_{2j} IPR_{i,t-j} + \varepsilon_{1it} \tag{3c}$$

$$TMK_{it} = \alpha_{TMK} + \sum_{j-1}^{p} \beta_{4j} TMK_{i,t-j} + \sum_{j-0}^{q} \gamma_{4j} GEF_{i,t-j} + \sum_{j-0}^{r} \delta_{4j} GDP_{i,t-j} + \varepsilon_{1it} \tag{3d}$$

$$GEF_{it} = \alpha_{GEF} + \sum_{j-5}^{p} \beta_{5j} GEF_{i,t-j} + \sum_{j-0}^{q} \gamma_{5j} TMK_{i,t-j} + \sum_{j-0}^{r} \delta_{5j} GDP_{i,t-j} + \varepsilon_{1it} \tag{3e}$$

IPR_{it} represents intellectual property right for country i at time t. $GDPPC_{it}$ represents GDP per capita for country i at time t. $R\&D_{it}$ represents research and development for country i at time t. α_{IPR} , α_{GDPPC}, and $\alpha_{R\&D}$ are intercept terms for each equation. β_{1j}, β_{2j}, and β_{1j} are lag coefficients for the respective variables in each equation. γ_{1j}, γ_{2j}, and γ_{3j} are coefficients representing the contemporaneous relationships between variables. δ_{1j}, δ_{2j}, and δ_{3j} are coefficients capturing the impact of lags of other variables on the current variable. $\varepsilon 1it$, $\varepsilon 2it$, and $\varepsilon 3it$ are error terms. In this PVAR system, we model how changes in financial development, environmental policy, and environmental sustainability affect each other over time. We choose appropriate lag lengths (p, q, r) based on the dynamics of our data and perform further diagnostics and tests to refine the model. Additionally, we add control variables if necessary to capture other factors that may influence these relationships.

Impulse Response Function (IRF)

The impulse response function (IRF) is a powerful tool in panel data analysis. It allows us to assess the dynamic effects of a shock to one variable on other variables in a system. We consider a vector autoregressive (VAR) model with our

variables: intellectual property right (IPR), GDP per capita (GDPPC), denotes research and development (R&D), trademark (TMK), and government effectiveness (GEF). We denote these variables as

$$Y_t = \left[IPR_{t,}GDPPC_{t,}R\&D_t, TMK_tGEF_t\right] \tag{4a}$$

The IRF for a given variable, e.g., IPR, to a shock in another variable, e.g., GDPPC, at a specific lag, can be represented as follows.

$$IRF_{IPR\rightarrow GDPPC,h} = \frac{\partial IPR_{t+h}}{\partial GDPPC_t} \tag{4b}$$

IPR_{t+h} is the value of intellectual property right at time $t+h$ after the shock. $GDPPC_t$ is the value of GDP per capita at time t. This equation quantifies how a one-unit shock to GDPPC at time t affects the future values of IPR at time $t+h$. We can extend this equation to compute IRFs for various combinations of shocks and variables in our VAR model, allowing us to analyze the dynamic responses of our variables to different shocks over time.

Variance Decomposition

In time series analysis, variance decomposition is a technique that helps determine how various shocks or factors contribute to the total variance of a variable of interest in a vector autoregressive (VAR) model. Our variables of interest, intellectual property right (IPR), GDP per capita (GDPPC), research and development (R&D), trademark (TMK), and government effectiveness (GEF), are included in a VAR model with k variables. These variables are designated as

$$Y_t = \left[IPR_{t,}GDPPC_{t,}R\&D_t, TMK_tGEF_t\right] \tag{5a}$$

The variance decomposition for the variable IPR at a specific horizon h can be represented as follows:

$$V_{IPR}^{(h)} = \sum\nolimits_{i-1}^{k} \left(\frac{\sigma_{IPRi}^{(h)}}{\sigma_{IPR}^{(h)}} \right) \times 100 \tag{5b}$$

where $V_{IPR}^{(h)}$ is the proportion of the variance of IPR at time explained by each variable. $\sigma_{IPRi}^{(h)}$ is the variance of IPR at time h due to the shocks from variable i. $\sigma_{IPR}^{(h)}$ is the total variance of IPR at time h. We can determine which causes or shocks have the most effects on IPR by using this equation, which shows us how much each variable contributes to the variation in IPR at a given time horizon. We perform variance decomposition calculations for several time horizons to observe the temporal evolution of the contributions and to obtain an understanding of the relative significance of various shocks or variables in explaining the variation in IPR.

Granger Causality

Granger causality testing can be used in a panel vector autoregression (PVAR) model to ascertain whether one variable can predict another. In a PVAR model, the general formula for determining Granger causality between two variables, such as Variable X and Variable Y, is as follows: With a PVAR model, we may investigate whether GDP per capita (GDPPC) Granger is a cause of intellectual property rights (IPRs).

The null hypothesis for Granger causality is typically stated as follows:

H0 (Null Hypothesis): GDPPC does not Granger cause IPR.

To test this null hypothesis, we can estimate two different PVAR models:

Model 1: This model includes only lags of IPR as predictors.

$$IPR_{it} = \alpha_i + \sum_{j-1}^{p} \beta_j IPR_{i,t-j} + \in_{it} \tag{6a}$$

Model 2: This model includes lags of both IPR and GDPPC as predictors.

$$IPR_{it} = \alpha_i + \sum_{j-1}^{p} \beta_j IPR_{i,t-j} + \sum_{j-1}^{p} \gamma_j GDPPC_{i,t-j} + \in_{it} \tag{6b}$$

i represent the individual or panel member. t represents the time. $IPR_{i,\,t}$ is the intellectual property right variable for individual i at time t. $GDPPC_{i,\,t}$ is the GDP per capita variable for individual i at time t. αi is an individual-specific intercept. βj and γj are coefficients. $\in_{it}$ is the error term.

Robustness Test and Preliminary Analysis

We must take care of any endogeneity concerns in our study prior to adding instrumental variables (IVs) to our model. When independent variables in our regression model have a correlation with the error term, it is known as endogeneity and results in skewed parameter estimates. We carefully check if variables like intellectual property right, GDP per capita, research and development, trademark, and government effectiveness exhibit endogeneity that could skew our results to assure the integrity of our findings. To this end, we use a two-phase method. The variables in our model that may be endogenous are first identified. To reduce the possibility of endogeneity bias, we secondly choose suitable IVs that have a correlation with these endogenous predictors but not with the error term.

We extend our model to include IVs. The generalized form of our model:

$$lnIPR = \ln(\alpha) + \beta ln(GDPPC) + \gamma ln(R\&D) + \eta ln(TMK) + \zeta ln(GEF) + \ln\left(\varepsilon_i\right) \tag{7}$$

In this equation, *lnIPR* denotes the natural logarithm of the dependent variable (intellectual property right); ln(α) represents the intercept; and β, γ, and ŋ are the coefficients for the natural logarithms GDP per capita, research and development, trademark, and government effectiveness, respectively. The term ln(ε_i) accounts

Table 2 Pesaran cross-sectional dependency results by countries

	CD-Test		CD2-Test	
	G20	DEVP	G20	DEVP
lnIPR	38.770***	9.530**	38.790***	33.320**
lnGDPPC	33.600***	57.220**	33.620**	52.980***
lnR&D	9.250***	9.070***	9.250***	8.870***
lnTMK	18.860***	2.180**	18.860***	3.150***
lnGEF	9.520***	43.590***	9.520***	43.630**

***and ** denote significance at 1% and 5% levels, respectively

Table 3 Cointegration and slope homogeneity results

Westerlund (2007) Cointegration			Pesaran and Yamagata (2008) Slope Homogeneity		
	G20	DEVP		G20	DEVP
Gt	−2.476***	−2.620**	Δ	12.810 ***	12.604 **
Pt	−9.569***	−11.124**	ΔAd	15.925***	15.678 **
Ga	−5.583***	−5.497 ***			
Pa	−5.040**	−4.110**			

***and ** indicate significance at 1% and 5% levels, respectively

for the error term. This extended model allows us to address endogeneity concerns and derive more robust and unbiased parameter estimates.

Preliminary Analysis

Cross-Sectional Dependency and Slope Homogeneity Testing

The Pesaran (2004) and Pesaran (2015) cross-sectional dependency test results for the respective countries are presented in Table 2. The outcomes of the CD-test and CD2-test for Pesaran (2004) and Pesaran (2015), respectively, are shown. The significant cross-sectional dependency among the series is the alternate hypothesis. The findings provide evidence in favor of cross-sectional dependency in both developing and G20 nations (refer to Table 2). It is suggested that the second-generation unit root test be used to check for a unit root in this study because of the presence of CD in the panels (Musah et al., 2021). This test is robust and reliable.

Westerlund (2007) Cointegration and Pesaran and Yamagata (2008) Slope Homogeneity Results

Pesaran and Yamagata (2008) test results, which are displayed in Table 3, correspondingly reveal that the null hypothesis of slope homogeneity for all samples is rejected. Therefore, heterogeneous panel data models will be suitable for this kind

of study. The bootstrap methodology was utilized. Among the findings from Westerlund (2007) are Gt, Ga, Pt, and Pa.

Panel Unit Roots Results

Table 4's CIPS and CADF results demonstrate that while some variables are stationary at first difference, others are significant at a level across nations. It indicates that while some variables are stationary at a level, others are not. GDPPC, R&D, TMK, and GEF were stationary at a level across G20 panel. Similarly, only IPR, GDPPC, and TMK are stationary at the level in the developing countries. Nonetheless, all the variables are stationary at first difference. The outcomes show a combined stationary at level I(0) and, at the first difference, I(1). The variables display the characteristics of I(0) and I(1), according to the unit root results, indicating that panel econometric models that address I(0) and I(1) should be used to assess the study's data (Ntarmah et al., 2022; Pesaran, 2003).

Benchmark Model and Robustness Test (IV Results)

From Table 5, the results from the analysis of GDPPC, R&D, TMK, and GEF in both G20 and developing countries provide valuable insights into the factors influencing IPR. These findings help us understand the diverse dynamics at play in these selected countries.

In G20 countries, the results reveal that economic growth (GDPPC) has a significant positive relationship with IPR. This suggests that whenever there is an improvement in GDPPC, IPR tend to increase. In the same vein, research and develop (R&D) show a significant positive association with IPR in the G20 countries. In other words, huge investment in R&D is linked to high IPR. Similarly, TMK also

Table 4 Panel unit root results

	CIPS				CADF			
	G20	Trend	DEVP	Trend	G20	Trend	DEVP	Trend
Level								
lnIPR	−1.54**	−2.37***	−2.45**	−2.50***	−1.47***	− 2.32***	−2.06***	−2.39***
lnGDPPC	−1.49***	−2.26***	−2.10***	−2.42***	−1.46***	−2.36**	−1.98**	−2.18***
lnR&D	−1.30***	−1.96***	−1.99	−2.30**	−1.19**	−1.67***	−1.65***	−1.61***
lnTMK	−2.21**	−2.67 ***	−2.54***	−3.27**	−1.51***	−2.10***	−1.94***	−2.76***
lnGEF	−2.35**	−2.48**	−2.61**	−2.22 ***	−1.32***	−1.34***	−1.41***	−1.96***
First difference								
lnIPR	−3.81***	−3.82***	−3.64***	−3.91***	−2.73***	−2.82***	−2.75***	−2.84**
lnGDPPC	−3.01***	−3.21***	−3.244**	−3.36**	−2.38***	−2.46***	−2.41**	−2.44***
LnR&D	−3.51***	−3.53**	−3.75***	−3.92**	−2.23***	−2.23***	−2.89***	−3.11***
lnTMK	−3.96***	−4.17***	−4.17***	−4.28***	−2.48***	−2.70**	−3.33**	−3.57***
lnGEF	−3.99***	−4.45**	−4.15***	−4.11**	−2.11**	−2.63***	−2.54***	−2.53**

***, **, and * denote significant at 1%, 5%, and 10% significance levels, respectively

Table 5 IV result

Dependent var.	G20 IPR	DEVP IPR
lnGDPPC	0.097*** (0.047)	0.168** (0.047)
lnR&D	0.288*** (0.045)	1.114 (0.060)
lnTMK	0.270** (0.066)	0.859*** (0.079)
lnGEF	0.184* (0.099)	0.011 (0.123)
_cons	18.974*** (0.911)	12.888*** (0.962)
Prob > chi2	0.000	0.000
Wald chi2(4)	73.44	523.11

***, **, and * denote significant at 1%, 5%, and 10% significance levels, respectively

shows a significant positive relationship with IPR, indicating that in the G20 countries with more trademark investment tend to promote intellectual property right. Finally, government effectiveness (GEF) also exhibits significant positive associations with IPR, indicating that obtaining IPR in a particular country is the responsibility of the government (Bannerman, 2020).

In the developing countries, the findings present a unique perspective. GDPPC, TMK, and GEF show significant positive relationship with IPR, highlighting that enhancing economic growth, trademark, and government effectiveness can lead to increase and improvement in IPR in these selected developing countries. Conversely, the result for the relationship between R&D and IPR highlights different dynamics. Thus, R&D has no significant relationship with IPR in the developing countries. Notably, the lack of a significant relationship between R&D and IPR suggests that the limited investment in R&D in the developing counties may not be a significant driver of IPR (Ilie, 2014).

These results underscore the importance of tailoring IPR policies and strategies to the specific context of G20 and developing countries. While R&D play critical roles in promoting IPR in the G20 countries, it is are less considered in the developing counties when looking for strategic way and factors to improve IPR.

Interaction Effect of IPR with GDPPC, R&D, and TMK

Table 6 below provides the interaction between IPR (GDPPC, R&D, and TMK) in both G20 and developing countries offer compelling insights into the complex interplay of these factors and their implications for IPR.

In G20 countries, the interactions reveal a multifaceted relationship between several factors and IPR. When GDPPC and R&D both increases, as denoted by the positive and highly significant (0.131), there is a substantial increase in IPR. This underscores the potential for combining economic growth and research and development to effectively improve and promote intellectual property right in the G20 countries. However, a nuanced observation emerges when examining the interaction of GDPPC and TMK (0.011). While this interaction is small, it is statistically significant and suggests that when both economic growth and trademark increase, there

Table 6 IV result

Dependent Var	G20 IPR	DEVP IPR
lnGDPPC*lnR&D	0.131 ***(0.062)	0.121**(0.040)
lnGDPPC*lnTMK	0.011***(0.003)	0.105***(0.007)
lnR&D*lnTMK	0.072**(0.048)	0.42*(0.054)
lnGEF	371**(0.099)	0.525**(0.087)
_cons	21.060 ***(0.355)	16.557 ***(0.470)
Prob > chi2	0.000	0.000
Wald chi2(3)	67.99	553.20

***, **, and * denote significant at 1%, 5%, and 10% significance levels, respectively

is a modest but significant impact on increasing IPR. Conversely, the interaction of R&D and TMK 0.072) reveals that the joint increase of research and development and trademark leads to a notable improvement in IPR in the G20 countries.

In the developing countries, a distinct set of dynamics emerges from the interactions. When GDPPC and TMK increase, there is a higher significant increase in IPR (GDPPC* TMK: 0.105), highlighting the importance of economic growth and trademark in achieving and promoting IPR in the developing countries. Also, the simultaneous increase in GDPPC and R&D leads to increase in IPR (GDPPC* R&D: 0.121), suggesting that economic growth and R&D are essential to IPR in the developing countries. The interaction of R&D and TMK (R&D*TMK: 0.42) results in a marginal increase in IPR when both variables increase, although the effect is less robust compared to G20 countries. This highlights the need for tailored IPR policies to address the unique context of the selected countries.

Result and Discussions

PVAR Results

The estimated PVAR results for the G20 and developing countries are shown in Table 7 below. These results are important and policy-relevant for comprehending the link between intellectual property rights, economic growth, research and development, trademarks, and government effectiveness. The following major discoveries and their ramifications are significant in the context of G20 countries. A prominent discovery emphasizes a noteworthy and affirmative link between IPR and GDPPC in the G20 nations. The coefficient of 0.013 ($p < 0.05$) indicates that improving access in GDPPC has a favorable impact on growing IPR supporting researchers who have looked at how economic growth in the G20 countries promotes IPR (Bannerman, 2020; Neves et al., 2021; Viglioni et al., 2023; Yu, 2016). This finding has important policy ramifications. Governments and policymakers in G20 countries should consider boosting IPR by promoting economic growth. This could be achieved by improving and granting more IPR to business and individual inventors. G20

Table 7 PVAR results

VAR	lnIPR	lnGDPPC	lnR&D	lnTMK	lnGEF
			G20		
lnIPR	0.819*** (0.030)	0.132** (0.037)	0.016** (0.009)	0.129** (0.075)	−0.270* (0.116)
lnGDPPC	0.013*** (0.022)	0.856*** (0.040)	−0.005** (0.002)	−0.181* (0.074)	0.018* (0.099)
lnR&D	0.104** (0.036)	0.466** (0.070)	0.014** (0.003)	−0.077** (0.099)	−0.475 (0.221)
lnTMK	0.038** (0.030)	0.205*** (0.037)	0.008 (0.006)	1.275** (0.074)	0.321 (0.099)
lnGEF	0.129*** (0.015)	0.134** (0.022)	0.001** (0.006)	0.104** (0.048)	0.878** (0.058)
			DEVP		
lnIPR	0.142** (0.208)	0.425*8 (0.365)	1.993** (1.066)	0.245* (0.585)	0.327*** (1.774)
lnGDPPC	0.088** (0.077)	0.911 (0.129)	0.196*** (0.314)	0.095 (0.191)	0.613** (0.625)
lnR&D	−0.059 (0.061)	0.209 (0.103)	0.461 (0.275)	0.248 (0.162)	−1.176* (0.537)
lnTMK	0.182** (0.201)	0.204** (0.344)	0.489** (0.874)	0.874* (0.526)	0.067** (1.745)
lnGEF	0.117** (0.052)	0.157* (0.096)	0.183* (0.234)	0.115* (0.146)	1.048** (0.475)

***, **, and * denote significant at 1%, 5%, and 10% significance levels, respectively

countries should establish well-functioning and vibrant IPR offices to enhance the number of IPR granted in a year. Consequentially, there is positive and significant connection between R&D and IPR in the G20 countries, indicated by coefficient of 0.104 ($p < 0.05$), suggesting that an increase in the R&D is associated with an increase in IPR in the G20 countries. The outcome is like the study of Ayerbe et al. (2023), Genin et al. (2022), and Magelssen (2020). This finding may emphasize the need for the various governments and policymakers to carefully assess and increase the investment made in research and development since an increase in R&D has a positive repercussion on IPR. Paying much attention and developing strong research base will induce and improve IPR in the G20 countries.

The analysis of relationship between TMK and IPR showed a significant and positive relationship with a coefficient of 0.038 ($p < 0.001$), suggesting a strong link between TMK and IPR. In the context of G20 countries, granting trademark to business and individual inventors facilitates IPR. This finding is in line with the findings of the following studies (Castaldi et al., 2022; Krasnikov & Jayachandran, 2022). The outcome was reached because TMK provides a monitoring system for brand owners to discern actions that may lighten their IP. It also serves as legal mechanisms to grant property rights for brand assets. In the same vein, there is a positive relationship between GEF and IPR. The coefficient of 0.129 ($p < 0.001$) suggests a strong and statistically significant positive relationship between government

effectiveness and IPR. This indicates that the various governments are responsible of establishing high-quality IPR policies and having a strong commitment to putting such policies into practice. Most of the G2O countries have taken over the years towards strong governance, regulatory, and policy-making capacities, including the TRIPS (Khan et al., 2023; Papageorgiadis et al., 2020).

The following major discoveries and their ramifications are important in the context of these developing nations: The considerable and highly significant positive link between GDPPC and IPR, with a substantial coefficient of 0.088 ($p < 0.001$), highlights the crucial role that economic growth plays in the results. This finding emphasizes that improving economic growth can profoundly impact the IPR in the developing countries. Government and policymakers in these countries should strategically and actively grow their economies since it plays a pivotal role in increasing IPR of inventors. This result was achieved since most developing countries focus on improving the economic situation of their perspective countries which directly promotes IPR (Viglioni et al., 2023; Bielig, 2015. Also, the link between GEF and IPR in the developing countries is significantly positive with the coefficient 0.117 ($p > 0.05$). This suggests that effective IPR policy implementation is contingent on government effectiveness that includes proper coordination of all stakeholders; thus, the process of achieving IPR strongly depends on IPR strategies developed by the government (Ma et al., 2022). Moreover, the results related to the link between TMK and IPR in the developing countries depicted positive and significant with the coefficient 0.182 ($p > 0.05$), suggesting that a percentage increase in TMK induces an increase in IPR (Peng et al., 2017). The relationship between research and development (R&D) and IPR is not statistically significant ($p > 0.05$); the coefficients of −0.059 suggest that the R&D may not be a significant determinant of IPR in the selected developing countries. This finding implies that an increase in R&D may not have a pronounced effect on IPR. This result may be ascribing to the fact that most developing countries are not reading to invest in research and development and do not pay much attention to inventors on innovative ideas. Policymakers may need to explore more tailored approaches or consider additional measures to effectively address R&D concern in these countries. This can be done by investing hugely on R&D (Abdin et al., 2024; Cho et al., 2015; Dass et al., 2021).

Considering the results, these conclusions provide insightful advice for both developing and G20 nations. Government and policymakers in G20 countries can capitalize on these results to promote a varied approach to increase IPR. This includes ensuring economic growth, increasing the investment in research and development, implementing strong trademark policy and increase the effectiveness of governance of IPR, encouraging, and motivating innovative and current ideas of business and individuals since innovation is the pivot of intellectual property. Furthermore, these insights extend to developing countries, where weak governance and scarcity in resources can lead to challenges in developing and implementing better policy (Ayerbe et al., 2023). They should be aware that aching IPR requires an improved economic growth, R&D. By considering these multifaceted strategies, the government can chart a path towards achieving IPR that addresses the unique challenges and opportunities within these developing countries, and invest heavily in R&D.

PVAR Granger Causality Test

The PVAR causality results in Table 8 below provide crucial insights for governments and policymakers seeking to promote intellectual property rights around the globe. This gives a critical knowledge of the differences in dynamics between G20 and developing countries. Both G20 and developing countries are confronted with different challenges and opportunities since they differ in economic characteristics and resources. We may get a complete understanding of the intricate connections between intellectual property rights, economic growth, research and development, and trademarks and government effectiveness by contrasting and comparing the results for each. In G20 countries, the PVAR causality results emphasize the interplay between IPR, GDPPC, R&D, TMK, and GEF. Notably, the significant causal link from GDPPC to IPR indicates that GDPPC can potentially improve the development and improvement in IPR in the G20 countries. This indicates that government and policymakers must consider the glorious impact of economic growth on intellectual property rights and act accordingly to improve IPR (Gervais, 2014;

Table 8 Granger causality result

	lnIPR	lnGDPPC	lnR&D	lnTMK	lnGEF
G20					
lnIPR		12.367*** (1.000)	3.363*** (1.000)	2.973 (1.000)	5.401 (1.000)
lnGDPPC	0.363*** (1.000)		4.814*** (1.000)	6.017* (1.000)	0.034 *** (1.000)
lnR&D	8.158* (1.000)	44.343 ** (1.000)		0.604** (1.000)	4.627* (1.000)
lnTMK	1.628** (1.000)	31.444** (1.000)	1.959** (1.000)		10.586** (1.000)
lnGEF	1.716** (1.000)	2.439** (1.000)	0.016** (1.000)	0.007** (1.000)	
ALL	17.881** (4.000)	9.127 *** (4.000)	71.282** (4.000)	37.181* (4.000)	23.347** (4.000)
DEVP					
lnIPR		1.356 * (1.000)	3.499 * (1.000)	0.176 (1.000)	0.034 (1.000)
lnGDPPC	1.327** (1.000)		0.391* (1.000)	0.246 (1.000)	0.963 (1.000)
lnR&D	0.937 (1.000)	4.105* (1.000)		2.334* (1.000)	4.796 (1.000)
lnTMK	0.823** (1.000)	0.354** (1.000)	0.313*** (1.000)		0.001** (1.000)
lnGEF	5.069 ** (1.000)	2.693** (1.000)	0.610** (1.000)	0.010 ** (1.000)	
ALL	17.331** (4.000)	15.524* (4.000)	6.803* (4.000)	1.493** (4.000)	6.236 ** (4.000)

***, **, and * denote significant at 1%, 5%, and 10% significance levels, respectively

Neves et al., 2021). Similarly, the strong causal link from R&D to IPR underscores how R&D can enhance IPR in the G20 countries. This connection empowers policymakers and G20 countries to commit more into R&D to boost and encourage IPR. Additionally, the causal connection from TMK, GEF to IPR in the G20 countries highlights the potential for trademark and government effectiveness to influence IPR (Castaldi et al., 2021; Krasnikov & Jayachandran, 2022).

In contrast, the PVAR causality results in developing countries offer distinguishing insights. The strong causal link from GDPPC to IPR accentuates the pivotal role of economic growth in ensuring intellectual property rights in the developing countries which are experiencing slow growth and development in GDP per capita. In the same vein, the strong causal link from TMK, GEF to IPR in the developing countries indicates the significant roles TMK and GEF play in achieving IPR in these developing countries. Government who are bent in promoting IPR should continuously invest in TMK and increase their effectiveness in the IPR policy making to consider them as strong boosters of IPR. However, the absence of a statistically significant causal link from R&D to IPR in the developing countries indicates that other factors play a more substantial role in achieving IPR (Coelli et al., 2022; Genin et al., 2022). It is imperative for governments and policymakers to investigate alternate approaches while recognizing the intricate interplay of R&D and IPR in these developing countries.

Together, these PVAR causality findings provide country-specific knowledge that enables policymakers to create and carry out focused policies. Policymakers may promote and improve economic growth and research and development in G20 and developing nations by addressing the opportunities and challenges they present. This will help to advance intellectual property rights. These findings are essential for steering the world towards more growth and promoting IPR in the future.

Variance Decomposition

Impulse responses do not establish the magnitude and extent of the effect, even if they can reveal details about how variations in one variable affect another. To find this, we therefore used variance decomposition techniques. The dependent series' percentage variations caused by shocks produced by other variables in addition to their own shocks can be found via variance decomposition. Table 9 displays the findings of the variance decomposition derived from the orthogonalized impulse response coefficient matrix. In this study, we interpret the decomposition of the error variance by focusing on GDPPC, R&D, TMK, and GEF to the variance of IPR at the tenth period only in which most variables have the highest explaining power than the others. To refine actionable steps for G20 countries and developing countries, it is imperative to relate the coefficient values in these results to policy implications.

The coefficient value of 0.303 (30.3%) for G20 countries highlights the significant impact of research and development (R&D) on intellectual property rights (IPR). Huge investment in research and development and flexible IPR policy frameworks should be implemented by policymakers and the various governments to achieve significant increase in IPR granted to inventors of their innovative ideas.

Table 9 Variance decomposition results

G20						DEVP				
	lnIPR	lnGDPPC	lnR&D	lnTMK	lnGEF	lnIPR	lnGDPPC	lnR&D	lnTMK	lnGEF
lnIPR										
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	1.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
2	0.965	0.005	0.007	0.012	0.010	0.665	0.026	0.304	0.003	0.001
3	0.897	0.017	0.009	0.048	0.030	0.547	0.028	0.391	0.003	0.032
4	0.788	0.034	0.009	0.114	0.055	0.479	0.025	0.389	0.003	0.105
5	0.649	0.055	0.008	0.209	0.079	0.433	0.027	0.356	0.003	0.181
6	0.499	0.077	0.006	0.320	0.098	0.403	0.040	0.324	0.004	0.229
7	0.363	0.095	0.005	0.430	0.107	0.381	0.065	0.307	0.005	0.242
8	0.254	0.109	0.003	0.524	0.110	0.362	0.096	0.303	0.006	0.232
9	0.176	0.117	0.002	0.596	0.108	0.342	0.124	0.305	0.006	0.222
10	0.124	0.122	0.002	0.648	0.104	0.318	0.142	0.303	0.006	0.230
lnGDPPC										
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.082	0.918	0.000	0.000	0.000	0.295	0.705	0.000	0.000	0.000
2	0.093	0.887	0.001	0.019	0.000	0.169	0.728	0.026	0.000	0.077
3	0.099	0.824	0.001	0.076	0.000	0.109	0.705	0.019	0.001	0.167
4	0.098	0.724	0.001	0.175	0.002	0.073	0.613	0.028	0.002	0.284
5	0.091	0.597	0.001	0.304	0.007	0.055	0.497	0.036	0.003	0.409
6	0.080	0.467	0.001	0.435	0.017	0.049	0.390	0.037	0.002	0.522
7	0.068	0.357	0.001	0.545	0.029	0.049	0.307	0.032	0.002	0.610
8	0.058	0.275	0.001	0.626	0.041	0.052	0.250	0.026	0.002	0.670
9	0.051	0.219	0.001	0.679	0.051	0.056	0.215	0.023	0.002	0.704
10	0.046	0.183	0.001	0.711	0.060	0.060	0.200	0.026	0.001	0.714
lnR&D										
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.003	0.007	0.990	0.000	0.000	0.036	0.154	0.809	0.000	0.000
2	0.003	0.009	0.987	0.000	0.001	0.026	0.136	0.709	0.003	0.126
3	0.003	0.010	0.984	0.001	0.002	0.027	0.105	0.579	0.005	0.284
4	0.003	0.012	0.980	0.003	0.002	0.032	0.084	0.468	0.007	0.409
5	0.003	0.014	0.974	0.006	0.003	0.038	0.078	0.394	0.009	0.481
6	0.003	0.016	0.965	0.012	0.004	0.042	0.089	0.354	0.011	0.504
7	0.004	0.019	0.948	0.024	0.005	0.044	0.110	0.341	0.012	0.493
8	0.005	0.023	0.919	0.045	0.008	0.043	0.136	0.342	0.012	0.466
9	0.007	0.030	0.871	0.081	0.012	0.041	0.157	0.345	0.012	0.444
10	0.010	0.039	0.794	0.139	0.018	0.039	0.167	0.340	0.012	0.443
lnTMK										
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.032	0.014	0.001	0.953	0.000	0.130	0.000	0.000	0.870	0.000
2	0.030	0.036	0.001	0.922	0.011	0.092	0.003	0.103	0.802	0.000
3	0.029	0.058	0.000	0.885	0.028	0.094	0.002	0.119	0.775	0.009

Table 9 (continued)

G20						DEVP				
	lnIPR	lnGDPPC	lnR&D	lnTMK	lnGEF	lnIPR	lnGDPPC	lnR&D	lnTMK	lnGEF
4	0.029	0.076	0.000	0.851	0.043	0.102	0.009	0.114	0.752	0.024
5	0.030	0.090	0.000	0.824	0.055	0.109	0.026	0.104	0.728	0.034
6	0.031	0.101	0.000	0.803	0.064	0.112	0.053	0.098	0.703	0.034
7	0.032	0.109	0.000	0.788	0.070	0.110	0.084	0.100	0.674	0.033
8	0.033	0.114	0.000	0.777	0.075	0.104	0.111	0.104	0.636	0.045
9	0.034	0.118	0.000	0.770	0.078	0.095	0.128	0.108	0.588	0.082
10	0.035	0.121	0.000	0.765	0.079	0.087	0.131	0.106	0.534	0.142
lnGEF										
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.004	0.042	0.000	0.062	0.892	0.148	0.073	0.025	0.091	0.662
2	0.002	0.034	0.000	0.064	0.900	0.094	0.065	0.138	0.078	0.626
3	0.003	0.027	0.000	0.069	0.902	0.089	0.042	0.118	0.061	0.690
4	0.005	0.022	0.000	0.077	0.896	0.092	0.035	0.089	0.049	0.734
5	0.009	0.020	0.000	0.090	0.881	0.097	0.046	0.075	0.041	0.741
6	0.015	0.021	0.000	0.112	0.852	0.099	0.073	0.077	0.037	0.714
7	0.022	0.025	0.000	0.146	0.807	0.097	0.109	0.093	0.034	0.667
8	0.029	0.034	0.000	0.197	0.739	0.092	0.143	0.115	0.032	0.618
9	0.036	0.048	0.001	0.267	0.648	0.084	0.166	0.133	0.029	0.588
10	0.042	0.064	0.001	0.353	0.540	0.077	0.171	0.140	0.026	0.587

Additionally, government effectiveness (GEF), with a coefficient value of 0.230 (23.0%), plays a significant role in achieving IPR. Policymakers and governments who want to improve IPR must focus on establishing effective governance such flexible and less expensive IPR registration. Trademark (TMK), with a coefficient value of 0.006 (0.6%), also contributes to IPR. G20 countries should manage resources optimally and explore economic growth indicators to promote and improve IPR (Ayerbe et al., 2023; Krasnikov & Jayachandran, 2022; Slimane & M'henni, 2020). Although GDP per capita (GDPPC) has a coefficient value of 0.142 (14.2%), smaller than that of R&D, it still contributes immensely to achieving IPR. Policymakers and governments should continually bend on improving and developing their economies to obtain resilient IPR (Bannerman, 2020; Hudson & Minea, 2013; Ilie, 2014; Laik, 2005).

In developing countries, the substantial coefficient value of 0.648 (64.8%) for trademark (TMK) highlights its profound impact on achieving IPR. Intensifying and promoting TMK in developing countries is pivotal for obtaining IPR (Ertekin et al., 2018). Research and development (R&D), represented by a coefficient value of 0.002 (0.2%), have a minor influence on achieving IPR in the developing countries, making it less of a priority for policymakers' governments. The coefficient value of 0.122 (12.2%) for GDPPC indicates its significant role in gaining IPR, although smaller than what was obtained in G20 countries. Adaptive strategies are necessary for developing countries to overcome challenges in implementing effective

economic growth policies. Government effectiveness (GEF), with a coefficient value of 0.104 (10.4%), still influences IPR and should be managed optimally.

These coefficient values provide quantifiable information on the roles played by the variables in obtaining intellectual property rights. G20 and developing nations can focus their tactics on more focused and effective interventions in the pursuit of intellectual property rights by connecting them to policy implications.

Impulse Response Function (IRF)

The impulse response function must be carried out to estimate PVAR, where a series of causative variables is necessary. Variables that emerge later in the framework are more endogenous and influence the preceding variable only with lag, whereas variables that arise earlier in a more exogenous sequence affect the subsequent variables simultaneously or even with lag, according to Sims (1980). We estimate orthogonal IRFs from shocks using Cholesky's decomposition, as proposed by Sims (1980), based on the literature. We focus on the interpretation of outcomes for the variable of interest (GDPPC, R&D, TMK, and GEF), as well as how they affect IPR. Figure 2 depicts the IRF findings of the influence of GDPPC, R&D, TMK, and GEF on IPR for the G20 and the selected developing countries (see Fig. 1).

The results in Fig. 1 exhibit that the impact of a one standard deviation rise (shock) in GDP per capita, research and development, and trademark on the G20's IPR is positive, but they are all modest throughout the time (1st to 10th year). This

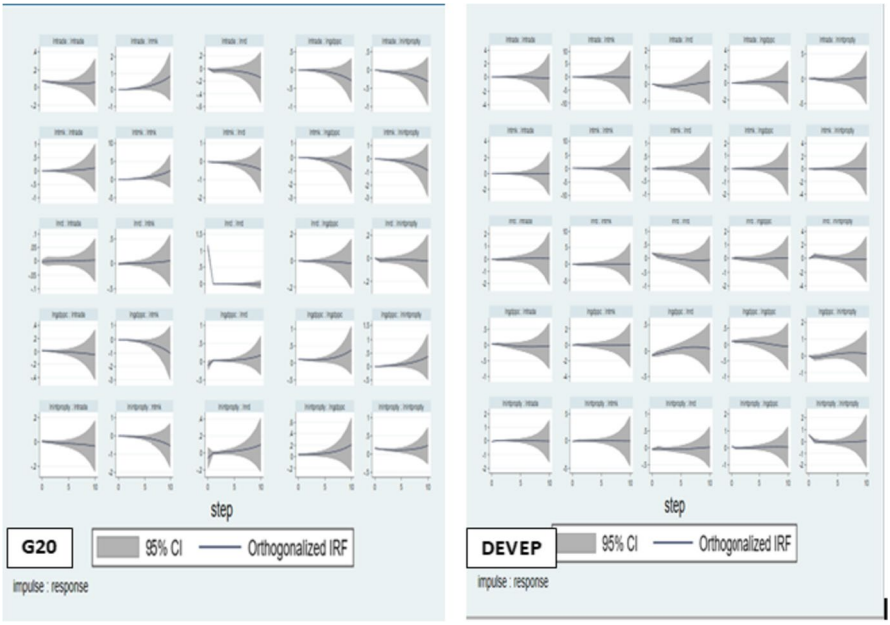

Fig. 1 Impulse–response results

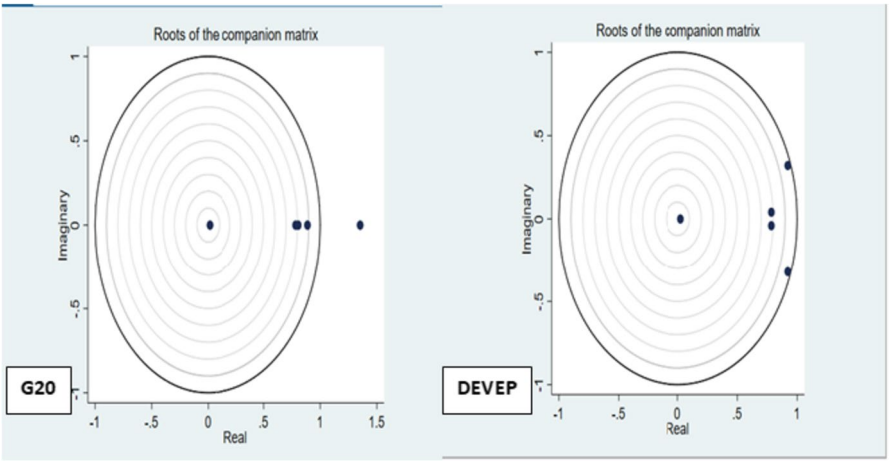

Fig. 2 Module stability

indicates that the G20's IPR responds favorably to GDPPC, R&D, TMK, and GEF shocks, showing that boosting the GDP per capita, research and development, trademark, and government effectiveness in the G20 countries raises IPR. The findings also point out that all the G20 countries are making strides in growing IPR. The findings complement the findings of Gyedu et al. (2021) and Hatemi-J et al. (2016).

Consequentially, the strong link between GDPPC, TMK, GEF, and IPR and a weak link between R&D and IPR suggest that the developing countries focus more on GDP per capita, trademark, and government effectiveness without considering the positive role that research and development plays in achieving IPR. According to the statistics, the elasticity of GDPPC, R&D, TMK, and GEF to IPR varies over time in the developing countries. The findings are in contradiction with the study of Gyedu et al. (2021) and Hatemi-J et al. (2016).

Model Stability

To ascertain how each endogenous variable in the panel VAR system would respond to an exogenous change in another variable, it is vital to verify the stability conditions of the PVAR estimate findings. The outcomes of the PVAR stability conditions are shown in Fig. 2 below. The estimated model's modulus, as determined by each eigenvalue, is less than one, or outside the outer circle. This suggests that the model is stable (Hamilton & Susmel, 1994).

Discussion of Results

The main objective of this study is to examine the relationship between intellectual property right, economic growth, research and development, trademark, and government effectiveness in the G20 and developing countries.

We discovered a positive and significant link between IPR and GDPPC in both G20 and selected developing countries. This indicates that an improved economic growth promotes IPR G20 and selected developing countries. This finding is similar to the findings of following studies (Bannerman, 2020; Neves et al., 2021; Viglioni et al., 2023; Yu, 2016).

Consequentially, there is positive and significant relationship between R&D and IPR in the G20 countries, suggesting that an increase in the R&D is associated with an increase in IPR in the G20 countries. The outcome is line with the study of Ayerbe et al. (2023), Genin et al. (2022), and Magelssen (2020). However, the relationship of R&D and IPR is not statistically insignificant, suggesting that an increase in R&D may not have a pronounced effect on IPR. Similar outcome was found in the following studies (Abdin et al., 2024; Cho et al., 2015; Dass et al., 2021).

The analysis of relationship between TMK and IPR showed a significant and positive relationship, suggesting that a rise in TMK costs a rise in IPR in both G20 and developing countries. This finding is in line with the findings of the following studies (Krasnikov & Jayachandran, 2022; Castaldi et al., 2022; Peng et al., 2017).

In the same vein, there is a positive relationship between GEF and IPR indicating that government effectiveness promotes IPR in both G20 and developing countries. Thus, a percentage increase in GEF induces an increase in IPR (Khan et al., 2023; Papageorgiadis et al., 2020; Ma, et al., 2022).

Conclusion and Policy Implications

This study examines the relationships among economic growth, research and development, trademarks, government effectiveness, and their impact on the attainment of intellectual property rights. It employs a distinctive panel dataset spanning G20 and developing countries from 2004 to 2022. The findings reveal a robust and significant connection between the independent variables, namely GDPPC, R&D, TMK, and GEF, and the dependent variable, IPR. This relationship becomes even more pronounced when focusing on enhancing GDPPC and intensifying R&D and GEF efforts in these countries. Employing methods such as panel vector autoregression (PVAR), PVAR Granger causality, variance decomposition, and impulse response functions (IRF), this analysis unveils the dynamic interactions between these factors. It underscores the pivotal role played by innovation-driven growth policies and economic development as the primary global drivers of IPR.

We discovered that economic growth, research and development, trademark, and government effectiveness have positive and significant effect on intellectual property right in the G20 countries (Ayerbe et al., 2023). The authors found out that economic growth, trademark, and government effectiveness have positive and significant influence on intellectual property rights, but research and development has no relationship with intellectual property right in the developing countries (Ertekin et al., 2018). Again, we detected that in the G20 countries, IPR responds favorably to economic growth, research and development, trademark, and government effectiveness shocks (Gyedu et al., 2021). Lastly, IPR responds favorably to economic

growth, trademark, and government effectiveness shocks in the developing countries (Hatemi-J et al., 2016).

This study contributes significantly to the existing literature in several ways. Firstly, it addresses gaps in the innovation-growth literature, particularly concerning the connection between intellectual property rights, economic growth, R&D investments, trademarks, and government effectiveness, which have hitherto yielded varying, inconclusive, and insufficient findings. Secondly, the results indicate that bolstered intellectual property rights can be achieved through a comprehensive strategy that encompasses robust economic growth, government effectiveness, substantial R&D investments, and well-designed trademark regulations, providing policymakers and governments with a fresh perspective. Moreover, this research considers country-specific variations by examining G20 and developing countries, offering a solid basis for cross-country comparisons and delivering results that authentically reflect these countries, thereby guiding IPR policies effectively. Additionally, it provides valuable insights into the path towards securing intellectual property rights in G20 and developing nations, employing panel vector autoregression, impulse response functions, PVAR Granger causality, and variance decomposition models to uncover the dynamic interactions between these variables. Lastly, the study not only highlights its findings but also offers practical and theoretical policy implications tailored to G20 and developing economies.

Practical Implications

The practical implications of this research are far-reaching, offering valuable guidance to stakeholders. For policymakers, the study emphasizes the need for tailored intellectual property strategies that align with a country's unique development goals. Industry leaders can make more informed decisions regarding intellectual property management and innovation strategies since digital innovations positively affect manufacturing firms' performance via innovation speed and operational efficiency due to the affordance of digital technology (Liu et al., 2023). This will aid innovators and entrepreneurs gain insights into how intellectual property protection can drive growth and market expansion. Intellectual property professionals can provide more precise guidance to their clients, while international organizations can adapt agreements to accommodate diverse member country needs. Academics can build upon these findings to advance theories in the multidisciplinary field of intellectual property, innovation, and economic development. In summary, this research equips a wide range of actors with a nuanced understanding of the complex connection between intellectual property rights, innovation, and economic growth, facilitating more informed and effective decision-making. Intellectual property right owners enjoy substantial benefits from their inventions which become essential to their respective societies and the countries at large since it provides them with quality life and important possessions.

Theoretical Implications

The theoretical implications of this study are significant. By delving into the complex link between intellectual property rights (IPR), innovation, economic development, and government effectiveness, this research contributes to filling literature gas and refinement of existing theories and the development of new theoretical frameworks. The study reveals that the causal relationship between IPR, innovation, and economic growth is multifaceted and context dependent. This nuanced understanding challenges oversimplified theoretical assumptions about the direct, linear impact of innovation and economic development on IPR. The theoretical implications extend to the necessity of considering sector-specific variations and the role of international agreements like TRIPS in shaping IPR policies. This nuanced perspective can lead to the evolution of existing theories in the domains of intellectual property, innovation, and development, enabling a more accurate and context-aware comprehension of the subject matter. The study's theoretical insights contribute to advancing and refining theoretical frameworks in these interrelated domains, enriching academic discourse and the development of future research.

Limitations and Future Applied Research

Even though this study was based on robust findings, the authors encountered the following study limitations. Before generalizations may be taken into account, this work only looked at some selected developed and developing counties, not specific countries. As a result, policy choices based on the study should consider the selected counties as a whole, rather than just individual countries. Also, this study combines residence and non-residence intellectual property rights which do not establish their individual impacts. This study applied only PVAR, PVAR Granger causality, and IRF without taking into account the other econometric methods. However, one avenue for future research is to conduct in-depth case studies in specific industries, considering the nuanced impact of IPR on innovation and economic development within each sector. This approach would provide a more granular understanding of how IPR affects diverse industries, offering practical recommendations tailored to each sector's unique characteristics. Additionally, examining the evolving landscape of international agreements related to intellectual property, such as TRIPS, and their impact on different countries and regions should be a priority. Furthermore, researchers can explore the role of emerging technologies, such as artificial intelligence and block chain, in the context of IPR, innovation, and economic development. Understanding how these technologies influence the dynamics of intellectual property and innovation is essential for guiding policy and strategic decisions in the digital era. Overall, future applied research should continue to address the practical implications of IPR on innovation and economic development while adapting to the evolving global landscape and technological advancements.

Appendix

Descriptive Statistics and Normality Results

The descriptive statistics of the variables chosen for this study reveal that there were 360 observations for G20 countries and 486 for developing countries, indicating that there were more developing (27 countries) than G20 (20 countries) in the study. Generally, the descriptive outcomes demonstrate that the data are not normally distributed. The Jarque-Bera and probability results serve as more evidence for this. Consequently, heterogeneous panel data models will be suitable for estimating the outcomes (Li et al., 2021).

	OBS	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis	Jarque–Bera	Probability
G20									
lnIPR	360	22.342	1.144	18.498	24.588	−0. 483	2.882	13.420	0.000
lnGDPPC	360	9.087	1.249	6.005	11.413	0. 140	2.297	8.109	0.010
lnR&D	360	0.365	1.266	−1.259	20.437	11.678	186.914	4.905	0.022
lnTMK	360	11.461	0.891	9.436	13.677	−0. 332	2.613	8.348	0.000
lnGEF	360	3.865	0.600	2.846	4.839	1.092	4.572	102.601	0.005
DEVP									
lnIPR	486	19.947	1.897	13.998	24.197	−0. 818	3.461	104.910	0.001
lnGDPPC	486	8.472	1.335	5.721	11.130	−0. 306	2.153	20.690	0.000
lnR&D	486	−0.128	1.076	−3.191	1.693	−0. 482	2.503	22.715	0.003
lnTMK	486	9.967	0.814	7.022	11.524	−0. 072	2.403	7.121	0.000
lnGEF	486	4.203	0.539	3.224	6.040	1.139	4.489	139.001	0.005

Correlation and Multi-collinearity Results

The correlation results in the appendix section show relationships between the explanatory variables and the outcome variable, indicating that the variables may be related. This offers a preliminary defense for researching how the explanatory variables affect the outcome variable. The collinearity statistics to determine whether there is multicollinearity among the explanatory variables. According to the general rule, the absence of multi-collinearity is indicated by a tolerance (Tol) value greater than 0.2 and a variance inflation factor (VIF) value lower than 5. According to the Table, the tolerance and VIF values indicate that multicollinearity is not a problem among the explanatory variables for the IPR model. The VIF values are less than 5 and the tolerance values are larger than 0.2, respectively.

	lnIPR	lnGDPPC	lnR&D	lnTMK	lnGEF	VIF	TOL
G20							
lnIPR	1						
lnGDPPC	0.124	1				1.090	0.916

	lnIPR	lnGDPPC	lnR&D	lnTMK	lnGEF	VIF	TOL
lnR&D	0.320	0.024	1			1.010	0.994
lnTMK	0.253	0.147	0.024	1		1.090	0.920
lnGEF	−0.094	0.215	0.069	−0.202	1	1.120	0.893
DEVP							
lnIPR	1					1.025	0.983
lnGDPPC	−0.076	1				1.020	0.979
lnR&D	0.644	0.112	1			1.152	0.868
lnTMK	0.409	−0.088	0.043	1		1.213	0.828
lnGEF	0.272	0.013	0.276	0.225	1	1.140	0.878

lnIPR is the dependent variable

VIF variance inflation factor; *Tol* tolerance

Data Availability The datasets generated and/or analyzed during the current study are available in the World Development Indicators repository, https://data.worldbank.org/ (accessed on 20 October 2023), and World Governance Index repository, https://info.worldbank.org/governance/wgi/ (accessed on 20 October 2023).

Declarations

Conflict of Interest The authors declare no competing interests.

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