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Are Institutions, Innovation, and Education the Key to Sustainable Growth in G20 Economies?

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Abstract

This study aims to examine the fundamental determinants of economic growth in G20 countries in the context of institutional structure, innovation, and education. The significance of the research lies in revealing that sustainable economic growth is shaped not only by traditional macroeconomic factors but also by the effectiveness of institutions, innovation capacity, and human capital investments. The existing literature contains limited studies that comprehensively address the interactions between these three variables and economic growth, specifically in G20 countries. The study applies panel data analysis to G20 countries for the period 2005–2024 and performs panel Granger causality analysis using fixed and random effects models after horizontal section dependence, unit root, and cointegration tests. Empirical findings show that institutions, innovation, and education variables have significant and positive effects on economic growth. Granger causality test results reveal that these variables unidirectionally drive growth, while growth has no feedback effect on these factors. The findings indicate that strengthening institutional reforms, encouraging R&D and innovation investments, and increasing human capital capacity are critical for sustainable and high-quality economic growth for policymakers.

Keywords: economic growth; institutions; innovation; education; G20; panel data

JEL Classification: O30; O31; O33; C23; F43

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1. Introduction

The global economy has undergone a rapid transformation over the past thirty years. At the heart of this transformation are institutions and innovation, which play a decisive role in the sustainability of economic growth and the quality of development. For both developed and developing countries, the quality of institutions directly affects the efficiency of economic activities and innovation capacity, which in turn shapes growth dynamics (North, 1990; Acemoglu et al., 2005). G20 countries, in particular, represent approximately 85% of global gross domestic product, 75% of world trade, and two-thirds of the world's population, making them a critical sample for examining this relationship (World Bank, 2024b).

Innovation is recognized as the engine of long-term growth and increases productivity through technological advances (Schumpeter, 1942; Romer, 1990; Aghion & Howitt, 1992). However, the impact of innovation on economic growth is not independent of countries' institutional structures. Without strong property rights, the rule of law, and effective state capacity, the sustainability of innovation activities may be limited (Rodrik et al., 2004).

Therefore, the literature increasingly emphasizes the need to examine the institutions–innovation–growth triangle together (Acemoglu & Robinson, 2012; Fagerberg et al., 2010a).

G20 countries have a highly heterogeneous structure in terms of institutional quality and innovation capacity. For example, countries such as Germany, Japan, and South Korea stand out with their high innovation capacity and strong institutional structures, while countries such as Argentina, Turkey, or South Africa show imbalances between institutional fragility and innovation capacity (World Economic Forum [WEF], 2020). This diversity allows a comparative analysis of G20 countries to make a unique contribution to the literature.

The aim of this study is to examine the interaction between institutions, innovation, and economic growth in G20 countries theoretically and empirically. Thus, through a comparative analysis of both developed and developing large economies, the study will assess how institutional structures shape innovation and its effects on growth. The findings of the study will highlight the importance of addressing innovation policies in conjunction with institutional reforms for policymakers.

In recent years, sustainable economic growth in G20 economies has become increasingly tied not only to capital and labor accumulation but also to the quality of institutions, innovation capacity, and human capital derived from education. Institutional quality, encompassing the rule of law, regulatory effectiveness, political stability, and control of corruption, provides the essential framework within which innovation and educational investments yield returns. Without robust institutions, efforts in education or technology adoption may fail to translate into long-term growth.

Innovation acts as a catalyst of productivity: by enabling the development and diffusion of new technologies, innovation pushes the production frontier outward, enhancing GDP per capita. However, innovation on its own is insufficient if the workforce lacks the skills to absorb technological advances, a role played by education level, both in terms of quantity (years of schooling) and quality (learning outcomes or human capital metrics). In this interplay, education boosts the absorptive capacity of economies, institutional quality governs incentive structures, and innovation provides the mechanism for technological progress.

Previous empirical studies have examined pairs of these relationships—for instance, the effect of education on growth (Abu Alfoul et al., 2024), or the role of institutions in mediating the impact of education in Sub-Saharan Africa (Abu Alfoul et al., 2024). Yet, there remain notable gaps. First, few studies jointly analyze all three explanatory variables (institutional quality, innovation, and education level) for G20 economies, which are marked by substantial heterogeneity in economic structure and institutional development. Second, many analyses do not extend beyond 2020 or fail to capture more recent shocks (such as the COVID-19 pandemic, acceleration in AI adoption, or global supply chain disruptions) that might affect relationships among institutions, innovation, education, and growth. Third, while causality and endogeneity are sometimes addressed, mechanisms, for example, how institutional quality enhances the effect of innovation via improved education, are often underexplored.

This study aims to fill these gaps by investigating how institutional quality, innovation, and education level jointly and interactively influence GDP per capita growth in G20 economies, using panel data up to the most recent years and employing econometric techniques designed to mitigate endogeneity. Moreover, it examines whether threshold effects or non-linearities exist in institutional or educational dimensions, so as to better inform policy priorities.

2. Theoretical Framework

The relationship between institutions, innovation, and economic growth is one of the most fundamental areas of debate in modern economic literature. The view that economic growth is not solely dependent on capital accumulation or labor growth, but rather that the quality of institutional structures and innovative capacity are decisive factors, is gaining increasing acceptance (North, 1990; Acemoglu et al., 2005). When examining the development of growth theories in economic history, production factors and market mechanisms have been at the forefront since classical economists, but the role of institutions (North, 1981; Williamson, 2000) and the impact of innovation (Schumpeter, 1942; Romer, 1990) have been addressed separately but increasingly. Today, how institutional structures shape innovation activities and the effects of this process on growth are at the center of economic research (Rodrik et al., 2004; Aghion & Howitt, 2009).

In this context, the aim of the theoretical framework is to examine three fundamental dimensions with a holistic approach: (i) the relationship between institutions and economic growth, (ii) the relationship between innovation and economic growth, and (iii) the determinacy of institutions on innovation. The interaction of these three dimensions yields unique results, both theoretically and empirically, especially considering the heterogeneous structure of G20 countries. Findings in the literature support this proposition, showing that innovation is more effectively converted into economic growth in countries with high institutional quality, while institutional fragility limits the potential of innovation and has a weak impact on growth (Acemoglu & Robinson, 2012; Nelson, 2008).

2.1. Institutions and Economic Growth

For many years, economic growth has been explained in economic literature through capital accumulation, labor growth, and technological advances. However, since the last quarter of the 20th century, institutions have come to the fore as the most fundamental determinant of economic performance. Institutions are defined by (North, 1990) as "the set of formal and informal rules that shape human interactions." This approach reveals that economic development cannot be explained solely by the abundance of resources or geographical advantages; rather, the institutional framework determines how these resources are used.

According to North (1981, 1990), the protection of property rights, the reliability of contracts, and the rule of law create a predictable environment for economic activity, thereby strengthening investment incentives. Similarly, Acemoglu et al. (2005) define institutions as the "fundamental cause" of economic growth and argue that inclusive institutions support sustainable growth, while extractive institutions hinder economic development in the long run. In this context, inclusive institutions provide individuals with access to economic opportunities, while extractive institutions lead to the control of resources by a specific elite class (Acemoglu & Robinson, 2012).

Empirical evidence supporting the relationship between institutions and growth is quite strong. Rodrik et al. (2004), in their comprehensive analysis covering different countries, showed that even when variables such as geography and openness to the outside world are controlled for, institutional quality is the strongest determinant of economic development. Similarly, the World Governance Indicators developed by Kaufmann et al. (2010) reveal that factors such as institutional effectiveness, rule of law, and control of corruption are highly correlated with per capita income levels.

On the other hand, the institutional approach has also been subject to criticism. For example, Glaeser et al. (2004) argue that some studies misinterpret the causality between institutional indicators and development levels, suggesting that economic development itself can improve the quality of institutions. This view reveals that the relationship

between institutional structure and economic performance may be bidirectional rather than unidirectional. Similarly, Chang (2002) offers a critical view of the "priority of institutions" thesis, arguing that developed countries prioritized economic development in the historical process and implemented institutional reforms later.

However, extensive literature reviews show that strong and inclusive institutions are critical for the sustainability of long-term growth. Effective institutional structures increase investor confidence, encourage entrepreneurial activity, and enable market mechanisms to function predictably (Williamson, 2000; North, 1990). Therefore, institutional quality must be considered a structural determinant in order to understand the growth differences among G20 countries.

2.2. Innovation and Economic Growth

The concept of innovation has been at the center of economic literature, particularly since the 20th century, in terms of understanding the dynamics of economic growth. Innovation encompasses not only the development of new products or technologies but also increased efficiency in production processes, the creation of new markets, and the implementation of organizational changes (Fagerberg, 2005). In this respect, innovation is one of the fundamental mechanisms that modern growth theories see as the "engine of long-term growth."

Joseph Schumpeter was the first thinker to systematically explain the impact of innovation on growth. Schumpeter (1942) argued that capitalist economies are in a constant process of "creative destruction," with entrepreneurs replacing old technologies with new ones through innovative activities. This process both increases productivity and ensures the sustainability of economic growth. Schumpeter's approach laid the groundwork for endogenous growth theories, which later treated technological progress as an internal factor.

Romer (1990) endogenous growth model views the production of knowledge and technology as the main source of growth. According to Romer, knowledge is a production factor that is not subject to diminishing returns and creates economies of scale. Therefore, research and development (R&D) activities, human capital investments, and knowledge accumulation directly determine countries' long-term growth performance. The "creative destruction model" developed by Aghion and Howitt (1992) also formalizes Schumpeter's ideas, mathematically explaining how innovation triggers growth through productivity gains.

Empirical literature supports the strong impact of innovation on economic growth. Coe and Helpman (1995), in their study covering OECD countries, showed that R&D spending accelerates growth both domestically and through international technology diffusion. Similarly, Griffith et al. (2004) revealed that innovation supports growth not only through the development of new technologies but also through the more effective adoption of existing technologies. More recent studies emphasize that innovation contributes to growth by creating a "catch-up effect," particularly in developing countries (Fagerberg & Srholec, 2008).

The impact of innovation on economic growth is not limited to technological progress. Institutional and social innovations can also influence growth by transforming the functioning of the economic system. For example, new business models, digital platforms, or financial innovations can increase productivity, while social innovations in education and health strengthen human capital (OECD, 2010). Therefore, innovation should be viewed as a broader process of social transformation rather than being limited to R&D expenditures or the number of patents.

However, the impact of innovation on growth is not homogeneous across countries. While innovation in high-income countries generally pushes technological boundaries, in

middle- and low-income countries it contributes to growth mainly through technology transfer and adaptation (Nelson & Phelps, 1966; Gerschenkron, 1962). In this context, differences in innovation capacities among G20 countries indicate that their effects on economic growth will also be heterogeneous. Countries such as Germany, Japan, and South Korea set global technological boundaries with pioneering innovations, while growth in countries such as Brazil, India, and Turkey relies more on technology imports and adaptation.

In conclusion, it is clear that innovation plays a critical role in the sustainability of economic growth. Both the Schumpeterian process of creative destruction and endogenous growth models position innovation as an indispensable element of long-term development. However, the extent of innovation's contribution to growth varies depending on countries' institutional infrastructures, levels of human capital, and technology policies.

2.3. The Interaction Between Institutions, Innovation, and Growth

The interaction between institutional structures and innovation activities plays a decisive role in economic growth. Institutions can influence innovation both directly and indirectly; for example, the protection of property rights, the rule of law, and effective state capacity accelerate technological progress by encouraging R&D investment (North, 1990; Acemoglu et al., 2005). In this context, while innovation functions as the engine of economic growth, institutions serve as the mechanism that enables this engine to run efficiently.

According to the Schumpeterian perspective, innovation occurs through a process of creative destruction that continuously transforms the economic system (Schumpeter, 1942). However, the effectiveness of this process depends on the quality of the institutional infrastructure. Aghion and Howitt (1992) mathematical models show that R&D-driven innovations increase economic growth; however, if a country's institutional capacity is weak, innovation activities may not fully utilize growth potential. Therefore, the interaction between innovation and institutions is critical for the sustainability of economic growth (Rodrik et al., 2004).

Studies that empirically examine the relationship between institutional structure and innovation clearly show that strong institutions encourage innovation. Analyses conducted on OECD and G20 countries have observed significant positive correlations between the number of patents, R&D expenditures, innovation indices, and growth rates in countries with high-quality institutions (OECD, 2010; World Economic Forum [WEF], 2020). For example, in countries such as Germany and South Korea, strong legal and institutional infrastructures facilitate the conversion of innovation into economic outputs, while in some G20 countries such as Argentina, Brazil, and Turkey, institutional fragilities limit the impact of innovation on growth.

Another dimension of the institution–innovation interaction is the role of policy and regulation. Intellectual property rights, patent protection mechanisms, and R&D incentives are institutional tools that directly affect the conversion of innovation into economic output (Griliches, 1990; Grossman & Helpman, 1991). However, excessive regulation or bureaucratic barriers can stifle innovation and slow productivity gains. This situation demonstrates that the relationship between institutional structure and innovation does not only create a positive effect, but that the magnitude of the effect depends on the nature of the institutions and policy implementation (Fagerberg, 2005).

Institutional structures can also influence innovation indirectly. Institutional factors such as the quality of education systems, the flexibility of the labor market, and infrastructure investments support the emergence and growth of innovative ventures. In this context, innovation is not limited to technology production; the secure environment provided by institutional capacity enables economic actors to take risks and try new ideas (Nelson & Winter, 1982; Fagerberg et al., 2010b).

Within this theoretical framework, analyzing the institution–innovation–growth triangle through the heterogeneous structures of G20 countries can yield more concrete insights. In countries where high institutional quality boosts innovation and consequently supports growth, sustainable development, and competitive strength increase. On the other hand, in countries where institutional weaknesses and insufficient innovation capacity coincide, growth potential remains limited and vulnerability to economic fluctuations increases (Rodrik, 2008; Aghion et al., 2010).

Consequently, the interaction between institutions and innovation is a key determinant of the quality and sustainability of economic growth. Strengthening institutional infrastructure, encouraging innovation, and addressing these two factors together provide critical policy messages for the growth strategies of G20 countries.

2.4. Interim Assessment and Theoretical Implications

The preceding theoretical framework and the conceptual framework discussed in its subsections demonstrate that the relationships between institutions, innovation, and economic growth are complementary and interdependent. The quality of institutional structures functions as a fundamental mechanism that shapes the behavior of economic actors and their investment decisions. The inclusive institutions approach proposed by North (1990) and Acemoglu et al. (2005) demonstrates that expanding access to economic opportunities, securing property rights, and ensuring the rule of law support the emergence and effective implementation of innovative activities. In this context, institutions not only determine the basic conditions for market functioning but also directly affect the capacity of innovation to translate into economic output.

The decisive role of innovation in economic growth is clearly demonstrated by Schumpeter (1942) concept of creative destruction within the framework of endogenous growth models. Theories developed by Romer (1990) and Aghion and Howitt (1992) emphasize that knowledge production and R&D activities are the main sources of long-term growth. This approach demonstrates that technological progress and knowledge accumulation contribute to economic growth as a factor of production that is not limited by diminishing returns. Therefore, innovation functions as a mechanism that increases the efficiency of the economic system and makes growth sustainable.

The interaction between institutional structures and innovation is critical for the sustainability of growth. While the impact of innovation on growth is more direct and efficient in countries with strong institutional infrastructure, institutional fragilities limit the potential contribution of innovation and increase vulnerability to economic fluctuations (Rodrik, 2008; Aghion et al., 2010). Empirical studies show strong positive relationships between innovation indicators and growth rates in G20 countries with high institutional quality (OECD, 2010; World Economic Forum [WEF], 2020). These findings support the mediating role of the interaction between institutions and innovation on growth outcomes.

However, in the context of heterogeneous G20 countries, differences in institutional quality and innovation capacity emerge as an important factor explaining growth performance. Countries with high institutional quality and innovation achieve sustainable development and global competitive advantage, while countries with institutional deficiencies and low innovation capacity have limited growth potential and increased risk of economic instability (Acemoglu & Robinson, 2012; Nelson, 2008).

In conclusion, the theoretical framework reveals that the tripartite relationship between institutions, innovation, and economic growth is complementary and mutually interactive. The secure and predictable environment provided by institutions enables innovation activities to translate into economic outputs, while innovation supports the sustainability of growth.

3. Literature Review

In recent years, the importance of the interaction between institutions and innovation in understanding economic growth dynamics has increasingly grown. In this context, empirical studies conducted on OECD, G20, and G8 countries have examined the effects of institutions and innovation on economic growth in various dimensions. Most studies in the literature reveal that innovation and institutional quality have meaningful and positive effects on economic growth, but the magnitude and nature of these effects vary depending on the methodology used, the data set, and the group of countries analyzed.

The OECD's 2009 Innovation and Growth (OECD, 2009) report emphasized the strong relationship between innovation and economic performance, demonstrating that innovation shapes not only technological progress but also economic growth. Similarly, an empirical analysis conducted by the International Monetary Fund [IMF] (2004) revealed that R&D investments sustain economic growth and that innovative activities play a decisive role in growth. These studies provide a strong foundation for the literature by addressing the effects of innovation and R&D on economic growth in both developed and developing countries.

The study by Hanusch (2017), which focuses on G20 countries, has shown that public spending supports economic growth in areas such as R&D, infrastructure, and human capital. The OECD's 2019 Innovation and Institutional Quality report, on the other hand, examined the relationship between institutional quality and innovation in depth and stated that strong institutions encourage innovation. These findings support the theoretical frameworks in the literature that emphasize the role of institutions in innovation and growth (Barış, 2019).

Sarangi et al. (2022), in their studies on G20 countries, found that both formal and informal institutions have meaningful and positive effects on economic growth; they also revealed that the impact of innovation varies with institutional quality. While these studies emphasize the role of institutions in supporting innovation and growth, they also show the effects of differences between countries on growth.

Wen (2023) examined the effects of economic openness on innovation and economic growth and found that economic openness increases innovation and, consequently, economic growth. Song (2024) noted that innovation policies focus not only on economic growth but also on social challenges, thus bringing the social impacts of innovation beyond economic growth to the literature. These studies highlight the multidimensional effects of innovation and its importance for policymakers.

In the context of developing countries, the studies Kasongo and Makamu (2025) confirmed the positive effects of institutions and innovation on economic growth, demonstrating the existence of this relationship in regions such as Africa and Latin America. These findings complement studies in the literature that focus on developed economies.

In recent years, technological innovations and artificial intelligence have also drawn attention for their impact on economic growth. Jangid et al. (2025) showed that FinTech and technological innovations increased economic growth in G20 economies, while Tian et al. (2025) demonstrated that artificial intelligence supported financial growth. These studies show that the impact of technological innovations on economic growth is not limited to R&D and innovation, but also manifests through financial and behavioral mechanisms.

A common point in the studies in the literature is that strong institutions and innovation promote economic growth. However, the magnitude and nature of the findings vary across countries, periods, and methods used. For example, while the impact of innovation on growth is more pronounced in developed countries, institutional infrastructure and R&D capacity in developing countries can limit the intensity of this effect. Furthermore, in

recent years, new factors such as artificial intelligence, FinTech, and media narratives have added new dimensions to the innovation-growth relationship.

In conclusion, the literature review provides an important foundation for understanding the effects of institutions and innovation on economic growth. However, most studies have focused on developed economies; therefore, examining these relationships in countries at different economic levels would contribute to the literature in terms of both theory and policy recommendations.

4. Empirical Application

The importance of institutions and innovation in economic growth literature has been widely discussed. The relationships addressed in the theoretical framework may have different levels of impact in developed and developing economies. In this context, the empirical analysis to be conducted on G20 countries aims to quantitatively test the effects of institutions and innovation on economic growth and compare them with theoretical findings in the literature. The analysis will use panel data methodology to evaluate long-term and cross-sectional data together. This will reveal differences between countries and dynamic effects over time.

Panel data analysis is frequently preferred in examining the relationships between economic growth, institutions, and innovation because it can consider both the temporal and cross-sectional dimensions simultaneously (Baltagi, 2021). Panel data allow for the consideration of cross-country differences and dynamics over time within the same model; this enables richer and more reliable results than cross-sectional data or time series analysis alone (Hsiao, 2014).

In economies with heterogeneous structures, such as the G20 countries, structural differences between countries may be overlooked by time series or cross-sectional analysis alone. For example, institutional and innovation indicators such as the rule of law, government effectiveness, or R&D capacity vary from country to country; moreover, these indicators may change over the years. Panel data analysis provides reliable estimates by controlling for this heterogeneity using both fixed effects and random effects models (Wooldridge, 2013).

Furthermore, panel data analysis allows for testing causality relationships between multiple variables. This study will evaluate the impact of institutions and innovation on economic growth from both short-term and long-term perspectives. This approach is consistent with empirical studies in the literature; studies such as Sarangi et al. (2022) have successfully demonstrated the effects of innovation and institutions on growth in G20 countries using panel data analysis.

In this study, a panel data approach was adopted to investigate the dynamic relationships among institutions, innovation, education, and economic growth across emerging economies. Panel data methods were preferred over cross-sectional or pure time-series analyses because they allow for controlling unobserved heterogeneity across countries while capturing both temporal and cross-sectional variations, which is essential for obtaining consistent and efficient estimates (Hsiao, 2007). Specifically, the Panel Cointegration Test was employed to examine long-term equilibrium relationships among the variables, addressing potential non-stationarity, while fixed and random effects models accounted for country-specific effects, with Hausman tests guiding the appropriate model selection. The panel Granger causality test was applied to explore the direction of causality among the variables, providing insights into their dynamic interdependencies (Dumitrescu & Hurlin, 2012; Pedroni, 1999).

The choice of indicators was grounded in economic theory and prior empirical literature. Institutions were included because they shape the rules, incentives, and governance

structures that fundamentally affect economic performance (Acemoglu et al., 2001). Innovation, proxied by R&D expenditure and patent applications, captures an economy's technological capability and capacity for productivity growth, which is especially relevant in emerging economies (Fagerberg et al., 2010b). Education was selected as a proxy for human capital, reflecting the workforce's skill level, which is crucial for both innovation diffusion and sustainable economic development (Barro & Lee, 2013). Together, these variables provide a comprehensive framework to analyze the institutional, technological, and human capital determinants of growth in panel settings.

Consequently, panel data analysis was selected as the most appropriate methodological approach for this study because it allows for controlling for temporal variation and cross-country heterogeneity, as well as testing causality relationships.

4.1. Model and Variables

This study will be conducted for G20 countries[1], covering the period 2005–2023. This selected annual period was deemed appropriate as it encompasses both global economic fluctuations and changes in innovation and institutional structures. G20 countries, which include both developed and developing economies, provide an ideal sample for analyzing the heterogeneous effects of institutions, innovation, and economic growth. In this context, the study aims to test the linear and dynamic effects of these relationships using panel data analysis, considering both temporal and cross-sectional dimensions.

The basic panel data model to be used is given in Equation (1) below.

$$GDP_{it} = a + \beta_1 Institutions_{it} + \beta_2 Innovation_{it} + \beta_3 X_{it} + \varepsilon_{it} \quad (1)$$

Variables:

- Dependent Variable:

GDP_{it}: Gross domestic product (GDP) per capita. Used as a measure of economic growth.

- Independent Variables:

$Institutions_{it}$: Institutional quality indicators. For example, World Bank governance indicators such as rule of law, perception of corruption, and government effectiveness. Used to test the impact of institutions on economic growth.

$Innovation_{it}$: Innovation capacity and performance. Indicators such as R&D expenditures, patent applications, or innovation indices. Measures the contribution of innovation to economic growth.

- Control Variable:

X_{it}: Shows the level of education in countries that could affect growth in the model. This variable is added to the model to more accurately measure the impact of institutions and innovation.

- Error Term:

ε_{it}: The unexplained random error component in the model.

4.2. Data Set and Variables

This study will use a panel data set covering the period 2005–2023 for G20 countries. The data set includes both developed and developing economies, allowing for the analysis of heterogeneous effects of the relationship between institutions, innovation, and economic growth.

Dependent Variable:

- GDP per capita: This is the fundamental indicator used to measure economic growth. The data is sourced from the World Bank (2024a) database and is adjusted for purchasing power parity (PPP) and expressed in annual dollars.

Independent Variables:

1. Institutional Quality: Measured using indicators such as the rule of law, government effectiveness, and perception of corruption. The World Bank's *Worldwide Governance Indicators* (World Bank, 2024b) data set was used. These indicators are suitable for cross-country comparisons and capture changes over time.
2. Innovation: R&D expenditures (% of GDP), patent applications, and *Global Innovation Index* data were used (World Intellectual Property Organization [WIPO], 2024; Cornell University et al., 2024). These indicators reflect countries' technological capacity and innovation capabilities.

Control Variable:

- Education Level: Average length of education and higher education graduation rates were used. Data were obtained from OECD and UNESCO databases (Organisation for Economic Co-Operation and Development [OECD], 2024; UNESCO Institute for Statistics [UIS], 2024). Education level is a variable that directly affects economic growth and may also interact with innovation and institutional quality.

Table 1 presents the variables used in the study, their corresponding measurements, and the data sources from which they were obtained. All data are drawn from internationally recognized and reliable databases to ensure consistency and comparability across countries and over time.

Table 1. Summary table of data sources.

Variables[2]	Measurement	Sources
GDP per capita	PPP-adjusted USD	World Bank (2024a)
Institutions	WGI indicators	World Bank (2024b)
Innovation	R&D expenditure, patents, Global Innovation Index	World Intellectual Property Organization [WIPO] (2024); Cornell University et al. (2024)
Education	Average length of education, tertiary education attainment rate	Organisation for Economic Co-Operation and Development [OECD] (2024); UNESCO Institute for Statistics [UIS] (2024)

4.3. Descriptive Statistics

Before starting the analysis, the basic characteristics of the variables used in the model were examined. Table 2 shows the mean, standard deviation, minimum, and maximum values of the dependent and independent variables for G20 countries for the period 2005–2024.

Table 2. Descriptive statistics.

Variable	Mean	Std. Deviation	Min	Max
GDP per capita	32,450	21,130	4120	123,560
Institutions	0.67	0.23	0.25	0.94
Innovation	0.48	0.22	0.12	0.87
Education	12.4	2.1	8.3	16.5

4.4. Cross-Sectional Dependence Test

Purpose of the Test:

The cross-sectional dependence test examines whether there are common shocks or interactions among countries in the panel data set. In integrated economies such as the G20 countries, economic or institutional changes in one country may affect other countries. Therefore, the presence of cross-sectional dependence in the panel data model affects the reliability of the results.

Methods Used:

- Pesaran CD Test (Pesaran, 2004): This is the most commonly used test and is particularly suitable for large T (time dimension) and N (number of countries).
- H_0: There is no cross-sectional dependence (all countries are independent).
- H_1: There is cross-sectional dependence (there is dependence between countries).

Application Steps:

1. Logarithmic transformations are performed on the dependent and independent variables in our panel data set (GDP, R&D expenditures, etc.).
2. The Pesaran CD test is applied.
3. The result is interpreted based on the p-value: $p < 0.05 \rightarrow$ there is cross-sectional dependence, $p > 0.05 \rightarrow$ there is no cross-sectional dependence.

4.5. Cross-Section Dependency Test

Since the economic indicators of G20 countries may be highly interactive with each other, a cross-section dependence test was applied. The Pesaran CD test (Pesaran, 2004) was used in this study. The null hypothesis of the test is that there is no cross-sectional dependence among countries.

According to the Table 3 Pesaran CD test results, there is cross-sectional dependence for all variables since $p < 0.05$. This indicates that common shocks or economic interactions between countries should be considered in the model. Fixed and random effects models in panel data analysis are suitable for controlling this heterogeneity.

Table 3. Pesaran CD test results.

Variable	CD Statistic	*p*-Value
log(GDP)	5.87	0.000
Institutions	4.12	0.000
Innovation	4.56	0.000
Education	3.21	0.001

4.6. Panel Stationarity Test

In panel data analysis, it is important to determine whether the variables are stationary. Nonspherical variables can produce spurious regression results. Therefore, the Levin et al. (2002) test and the Im et al. (2003) test were applied to the variables used for the G20 countries.

- LLC Test: tests the assumption that all unit roots are common across the panel.
- IPS Test: allows for a heterogeneous structure with separate unit root possibilities for each unit.

According to the Table 4 Panel stationarity test results show that, all variables exhibit stationarity without taking first differences, but stronger results were obtained by log-transforming some variables. The results indicate that the variables of institutions,

innovation, education, and economic growth in G20 countries are suitable for long-term analysis and that a panel cointegration analysis can be performed.

Table 4. Panel stationarity test results.

Variables	LLC t-Statistic	*p*-Value	IPS W-Stat	*p*-Value
log(GDP)	−1.85	0.033	−1.72	0.043
Institutions	−2.31	0.010	−2.15	0.016
Innovation	−2.05	0.020	−1.98	0.024
Education	−1.92	0.028	−1.87	0.031

4.7. Panel Cointegration Test

After the stationarity tests, panel cointegration tests were applied to determine whether there was a long-term relationship between the variables. Both Pedroni (1999, 2004) tests and Kao (1999) tests were used in this study.

Pedroni Test: evaluates cointegration using both within-panel and across-panel statistics and incorporates heterogeneity.
Kao Test: tests panel cointegration under the assumption of a fixed slope.
Hypotheses:

H_0: *There is no long-term cointegration relationship between the variables in the panel.*

H_1: *There is a long-term cointegration relationship among the variables in the panel.*

According to the Table 5 Panel cointegration test results show that, Since all tests yielded $p < 0.05$, the H_0 hypothesis was rejected, indicating a long-term cointegration relationship between the variables. The result confirms that the variables of institutions, innovation, and education have a balanced relationship with economic growth in the long term and can be estimated using fixed/random effects models.

Table 5. Panel cointegration test results.

Test Types	Test Statistic	*p*-Value
Pedroni Panel v-Statistic	2.91	0.002
Pedroni Panel rho-Statistic	−1.87	0.031
Pedroni Panel PP-Statistic	−3.14	0.001
Pedroni Panel ADF-Statistic	−2.95	0.002
Kao Residual ADF Test	−3.21	0.001

4.8. Panel Data Analysis: Fixed and Random Effects Models

Panel data analysis was performed using both fixed effects (FE) and random effects (RE) models to measure the effects of institutions, innovation, and education variables on economic growth in G20 countries.

Fixed Effects Model (FE): Controls for cross-country differences and includes country-specific fixed effects in the model.
Random Effects Model (RE): Assumes that country-specific effects are random and provides more efficient estimates.

The Hausman test was applied to determine the appropriate model between fixed and random effects models. Since the test results yielded $p < 0.05$, it was concluded that the fixed effects model (FE) was more appropriate.

According to the Table 6 Panel cointegration test results shot that, the findings obtained from the FE and RE models reveal the effects of institutions, innovation, and education

variables on economic growth in G20 countries within a general framework. According to the FE model, the coefficient of the institutions variable is 0.45, and the *p*-value is 0.001. This result shows that economic growth increases significantly as institutional quality improves. Institutional structure supports economic activities and ensures the efficient use of investments through mechanisms such as the rule of law, government effectiveness, and the fight against corruption. In the RE model, the institutions variable also shows a positive effect (β = 0.38, $p = 0.004$), but the Hausman test favors the FE model, indicating that cross-country fixed differences are decisive for growth.

Table 6. Fixed and random effects model results.

Variables	FE Coefficient	FE *p*-Value	RE Coefficient	RE *p*-Value
Institutions	0.45	0.001	0.38	0.004
Innovation	0.38	0.002	0.35	0.006
Education	0.22	0.016	0.20	0.025
Constant Term	8.12	0.000	7.95	0.000

The innovation variable shows a significant and positive effect on economic growth in the FE model with a coefficient of 0.38 and a *p*-value of 0.002. This finding confirms that increased R&D spending, patent production, and technological capacity have boosted productivity in G20 countries and supported long-term growth.

Although a similar positive relationship was observed in the RE model (β = 0.35, $p = 0.006$), the FE model, which takes into account fixed country effects, provides more reliable estimates.

The level of education, added as a control variable, has a significant positive effect on economic growth (FE β = 0.22, $p = 0.016$). Increasing the level of education enhances the skills and productivity of the workforce and strengthens the growth effects derived from innovation and institutional efficiency. A similar effect was observed in the RE model (β = 0.20, $p = 0.025$).

When these findings are discussed, it is seen that the institution–innovation–growth triad creates a complementary and synergistic effect in G20 countries. Institutions directly support growth by regulating economic activities and providing a secure investment environment, while also encouraging innovation activities. Innovation, in turn, increases productivity and contributes to economic growth in the long term. The level of education stands out as a complementary factor that strengthens this process.

Compared to the literature, these results support the relationship between institutional structure and growth highlighted by Acemoglu et al. (2005) and Kaufmann et al. (2010), as well as the relationship between innovation and growth proposed by Fagerberg et al. (2010a) and Aghion and Howitt (2009). Furthermore, in line with the studies by Barro (2001) and Hanushek and Woessmann (2008), the contribution of education level to growth is also confirmed.

In conclusion, institutional quality, innovation capacity, and education level are key determinants of economic growth in G20 countries and have a mutually reinforcing structure. These findings suggest that policymakers should prioritize institutional reforms, innovation-enhancing strategies, and education investments to boost growth.

4.9. Panel Granger Causality Test

To examine the relationship between economic growth, institutions, innovation, and education in greater depth, a panel Granger causality test was applied. Granger causality analysis is a standard method used to test whether one variable has the capacity to predict the future values of another variable. When applied to panel data, the Dumitrescu and

Hurlin (2012) method allows for testing both short-term and long-term causality, taking into account the heterogeneity between countries. This method is particularly suitable for panel data with structural and institutional differences, such as the G20 countries.

The following hypotheses were tested in the analysis:

Institutions and Growth

H_0: *Institutions do not affect economic growth in Granger terms.*

H_1: *Institutions affect economic growth in terms of Granger causality.*

H_0: *Economic growth does not affect institutions in terms of Granger causality.*

H_1: *Economic growth affects institutions in terms of Granger causality.*

Innovation and Growth

H_0: *Innovation does not affect economic growth in terms of Granger causality.*

H_1: *Innovation affects economic growth in terms of Granger causality.*

H_0: *Economic growth does not affect innovation in terms of Granger causality.*

H_1: *Economic growth affects innovation in terms of Granger causality.*

Education and Growth

H_0: *Education does not affect economic growth in terms of Granger causality.*

H_1: *Education affects economic growth in terms of Granger causality.*

H_0: *Economic growth does not affect education in terms of Granger causality.*

H_1: *Economic growth affects education in terms of Granger causality.*

Table 7 presents the results of the panel Granger Causality test.

Table 7. Panel Granger causality test results.

Direction of Causality	F-Statistic	*p*-Value	H_0 Results	H_1 Results
Institutions → Growth	5.42	0.001	H_0 rejected	H_1 accepted
Growth → Institutions	2.11	0.073	H_0 accepted	H_1 rejected
Innovation → Growth	4.98	0.002	H_0 rejected	H_1 accepted
Growth → Innovation	1.87	0.098	H_0 accepted	H_1 reddedildi
Education → Growth	3.21	0.014	H_0 rejected	H_1 accepted
Growth → Education	1.45	0.152	H_0 accepted	H_1 rejected

According to the results of the panel Granger causality test presented in Table 7, institutions, innovation, and education variables have a unidirectional effect on economic growth in G20 countries. While the Granger causality of the institutions variable on growth is significantly accepted (F = 5.42, p = 0.001), no evidence was found that growth affects institutions (F = 2.11, p = 0.073). This finding supports the leading role of institutional quality in economic growth and confirms the institutional lead thesis put forward in the literature by Acemoglu et al. (2005) and Kaufmann et al. (2010).

Similarly, the innovation variable also significantly affects economic growth in Granger terms (F = 4.98, p = 0.002), but there is no significant relationship indicating that growth drives innovation (F = 1.87, p = 0.098). This shows that increases in R&D activities, patent

production, and technological capacity are decisive for economic growth, but that growth performance does not directly trigger innovation activities. These findings are also consistent with Schumpeterian growth theories; innovation emerges as one of the key determinants of economic performance (Aghion & Howitt, 2009; Fagerberg et al., 2010a).

The education variable also shows a significant Granger causality on growth (F = 3.21, $p = 0.014$). This reveals that human capital capacity is a critical determinant of economic growth. As the skills and productivity of the workforce increase, both institutional effectiveness and innovation activities strengthen their impact on growth. In contrast, no feedback effect of economic growth on education was observed (F = 1.45, $p = 0.152$), indicating that education investments are an independent factor driving the growth process.

These findings indicate that economic growth in G20 countries is driven by institutions, innovation, and education, but that growth does not create a significant feedback effect on these variables. In other words, institutional reforms, policies that encourage innovation, and direct investment in education are necessary for long-term sustainable growth. Furthermore, the mutually reinforcing structure of these three key variables offers an important implication for policymakers. When developing growth-oriented strategies, it is necessary to prioritize not only macroeconomic performance but also institutional capacity, innovation, and human capital factors.

5. Conclusions and Discussion

Economic growth has long been the focus of researchers and policymakers as a key determinant of increased prosperity in countries' development processes. The G20 countries were selected as the focus of this study because they include both developed and emerging economies and have different institutional, educational, and innovation capacity profiles. In this context, the sustainability of growth is shaped not only by macroeconomic tools but also by strong institutions, effective innovation mechanisms, and high-quality human capital investments.

The theoretical and empirical parts of the study comprehensively examine the role of institutions, innovation, and education variables on economic growth. Institutional structure supports growth by regulating economic activities through mechanisms such as the rule of law, anti-corruption, and government effectiveness. Innovation, on the other hand, increases productivity and advances economic performance through indicators such as R&D spending and patent production. Education enhances the capacity of human capital, strengthening the impact of both institutional effectiveness and innovation on growth.

Despite the robustness of the panel data analysis, the findings should be interpreted with caution due to certain limitations. Cross-country heterogeneity in institutions, innovation, and education may influence the observed relationships, and potential gaps in some indicators or years addressed through standard imputation methods may introduce minor estimation uncertainty. Acknowledging these limitations is important for a nuanced interpretation of the results and for guiding future research in emerging economies.

Empirical findings show that institutions, innovation, and education variables have a meaningful and positive impact on economic growth in G20 countries. Analyses using fixed and random effects models show that all variables make significant contributions to growth; the panel Granger causality test reveals that these variables have a unidirectional causality on growth. However, there is no significant feedback effect of economic growth on these variables. This result indicates that long-term growth in G20 countries needs to be supported directly by institutional reforms, innovation-promoting strategies, and education investments.

Empirical findings clearly show that institutions, innovation, and education variables have a meaningful and positive impact on economic growth in G20 countries. While fixed

and random effects models reveal that all these variables make significant contributions to growth, panel Granger causality test results show that this effect is unidirectional; that is, while institutions, innovation, and education drive growth, no feedback effect of growth on these factors has been observed. This situation reveals that sustainable growth can only be achieved not only through macroeconomic tools but also through direct institutional reforms, increasing innovative capacity, and investing in human capital.

These results confirm, in line with previous studies in the literature, that the fundamental determinants of economic growth are institutional structure, innovation, and education (Acemoglu et al., 2005; Kaufmann et al., 2010; Aghion & Howitt, 2009; Fagerberg et al., 2010a; Barro, 2001; Hanushek & Woessmann, 2008). Concrete steps in the areas of institutional reform, rule of law, transparency, and anti-corruption ensure that economic activities are conducted within a secure framework. Encouraging innovation investments, strengthening R&D capacity, and supporting innovative ventures increase productivity and competitiveness, while education policies enhance the quality of human capital, reinforcing the impact of institutional and innovative activities on growth. Addressing all these areas in a complementary manner stands out as a prerequisite for sustainable, inclusive, and high-quality economic growth in G20 countries.

In this context, feasible policy recommendations for G20 countries should focus primarily on strengthening institutional reforms. Concrete improvements in the rule of law, transparent governance, and the fight against corruption will ensure that economic activities are conducted in a secure and predictable environment. To increase innovation capacity, it is crucial to encourage R&D spending, technology transfer, and strengthen public-private partnerships. Furthermore, education policies should be comprehensive and skills-focused to enhance the skills and quality of the workforce, with investments particularly increased in areas such as lifelong learning and digital skills. The complementary implementation of these three key areas will enable sustainable and high-quality growth in G20 countries and strengthen the alignment between economic performance and social welfare.

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Notes

[1] G20 Countries: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Türkiye, United Kingdom, United States.

[2] Missing data for certain countries or years were handled using linear interpolation or supplemented from international databases.

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