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Article

Does innovation and education affect economic growth? A data-driven approach using panel data

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Abstract: This study investigates the intricate relationship between a nation's GDP growth rate and three key variables: the number of granted patents, research and development (R&D) expenditure, and education expenditure. The purpose of the research is to discern the impact of these factors on GDP growth rates. Drawing on theoretical frameworks, including Dynamic Ordinary Least Squares (DOLS), Fully Modified Ordinary Least Squares (FMOLS), and Canonical Correlation Regression (CCR) techniques, the paper employs a robust methodological approach to unveil insights into the dynamics of economic growth. Contrary to conventional assumptions, the results reveal a negative correlation between R&D expenditure and GDP growth rate. In contrast, the number of patents granted and education expenditure shows a positively significant effect on the GDP growth rate, underscoring the pivotal roles of intellectual property creation and education investment in fostering economic growth. The conclusion emphasizes the importance of a nuanced understanding of these relationships for policymakers. The research's implications highlight the need for balanced investments in innovation and education. The originality and value of this study lie in its unique findings challenging established beliefs about the impact of R&D expenditure on economic growth.

Keywords: innovation; R&D; education; patent; economic growth

1. Introduction

The intersection of education, innovation, and economic growth constitutes a critical nexus within the field of economics, serving as a focal point for extensive research and analysis. Education, recognized as a fundamental pillar of economic progress, has long been associated with the accumulation of human capital—an essential driver of productivity and innovation. Investing in education, both in terms of its quality and quantity, significantly augments the reservoir of human capital. This, in turn, stimulates productivity and fuels innovative advancements within economies.

Countries boasting higher levels of education often experience accelerated rates of economic growth. This correlation extends across individual and national scales, as educated individuals tend to contribute more substantially to technological advancements and engage in higher-value economic activities. Furthermore, an educated populace often fosters improved governance, better health outcomes, and heightened social cohesion, all of which collectively bolster economic prosperity.

The advent of endogenous growth theories articulated by influential economists such as Lucas (1988), Mankiw et al. (1992) and Romer (1989, 1990) emphasized the intrinsic connection between human capital and production functions. Scholars like Becker (1962), Denison (1962), Mincer (1974), and Schultz (1961) contributed to the development of human capital theory, reinforcing the idea that investing in skills through education and training significantly influences the production process. Extensive theoretical frameworks established by Barro and Sala-i-Martin (2004), Greiner et al. (2005), Mankiw et al. (1992), and Romer (1989) further validate the positive association between human capital and economic growth, placing a significant emphasis on investing in human capital and knowledge-based economies as pivotal drivers for sustained economic expansion.

Innovation, akin to an investment in education, plays a pivotal role in fortifying competitiveness and progress, thereby fostering sustainable economic growth. However, the conceptualization of innovation in education remains multifaceted, traversing various academic disciplines such as sociology, psychology, economics, linguistics, management, cognitive science, and philosophy. Innovation, as a catalyst for economic growth, encompasses the creation and application of novel ideas, technologies, processes, and products that drive increased efficiency, productivity, and competitiveness.

Numerous studies, employing diverse methodologies and proxy variables, have scrutinized the relationships between education and economic growth, innovation and economic growth, as well as the intersection of innovation and education. These investigations, spanning various countries and timeframes, have significantly contributed to unraveling the complex dynamics underlying economic progress, shedding light on the interconnectedness and profound impact of education, innovation, and human capital on fostering sustained economic development.

Despite the broad uncovering of the interaction of education-innovation-economic growth, the complex linkages leading to the relationship become less examined. Most research is more empirical and cross-country or concentrates on details like R&D expenditure rather than the big picture. Meanwhile, research that has been more precise, and more multifaceted, with an overall consideration for various aspects of educational innovation, their determinants, and consequences on economic growth is missing. Thus, these findings support the need for mixed approaches research with quantitative techniques to project the various innovations and qualitative explanations to understand the change pathways in multiple nations. The fresh perspective of the review stems from the fact that it incorporates several educational innovations along with some parallel frameworks and checks their linkages to the current growth empirically while giving a theoretical explanation to shed light on the processes and provides tailored, evidence-based policy insights in the end. This novel mode brings together both the micro and macro perspectives by providing a distinct insight into how the differently catalyzed education innovations are linked to economic progress.

2. Literature review

2.1. Education and economic growth

Extensive research points out the vital link between education and economic development whereby countries directly link their performance with the level of education they have. Education is considered by many as the most important sphere that can be used to build human capital. At the school, individuals have the opportunity to develop their talents, knowledge, and abilities that are in line with the country’s productivity and innovation. The seminal works of Becker (1962) and Schultz (1961) were strikingly on education as a method of building human capital which in turn has a strong impact on the enhancement of workforce productivity and economic growth.

Educational research shows that both the quantity and quality of learners correlate with economic growth. More schooling and academic achievements are indeed important, but it is significant also to pay attention to the achievement of quality education—which includes relevant curricula, good teachers, and learning outcomes. The research by Hanushek and Woessmann (2008) shed light on the fact that there exists a direct connection between the number of years students have in schooling and their performance on achievement tests which in turn reflects the effectiveness of teaching and learning (Huang et al., 2011, Huang et al., 2021, Huang et al., 2022).

Education is a key element of technological advancement and innovation as their main driving force is development. It is educated people who are more likely to be engaged in research, engineering, and improvement of innovations. This hypothesis is also in line with work done by the scholars, Romer (1990) and Lucas (1988) around the importance of human capital in fostering innovations that later shape growth.

Aimed at this end, education has a powerful impact on reducing income inequality and contributing to social mobility. Many researchers equate quality education with increased socioeconomic opportunities: According to Chetty et al. (2017) and Hertz (2008), a high level of schooling is one of the factors that determine the chances of success for someone looking to advance in life, since it proves their knowledge and helps them earn more.

Considerable outcomes point at education as a money-saving investment that does not only benefit the individuals but even the society. A college or university graduate typically will have better income, more job opportunities, and increased well-being. Heckman (2006) addressed the perennial, long-term economic benefits of early childhood education, giving due credit to its value in the next steps.

In this regard, policymakers are busy with the reforms that enable equity, efficiency, and relevance of education systems like encouraging access to education, improving quality and linking education with job market requirements for economic growth. National research done by Barro and Lee (2013) and Hanushek and Woessmann (2015) conveyed the very significant economic role of education policies that prevail across nations.

2.2. Innovation and economic growth

The strong relationship between innovation and economic growth has been one of the topics in economic theory that has been researched repeatedly. Countless studies drive home that innovation is the main engine of economic growth, it occurs via the road like technological inventions, process modifications, pathbreaking products and services, and market disruptive models. Schumpeter pioneeringly designed the concept of innovation's function as the "creative destruction", whereby new products and technologies displace outdated ones contributing to economic prosperity.

Technological innovation significantly shapes productivity, delivering continuous efficiency improvements throughout coos. Solow's (1957) "Solow Residual" shows that the progress of technology is one of the influential factors behind the rhythm of economic growth, by determining output per unit of inputs increased, which might have led to the surge of aggregate productivity and market growth.

Coleman and Mills (1989) corporate-level examinations showed that an organization's innovative strengths such as good research and development budgets, as well as the availability of resources and supportive innovation systems, are directly linked to the innovation success and, therefore, the national economy.

Innovation is a multiplier effect and can cause positive externalities, as long as it is not limited to directly involved sectors. Arrow's (1962) and Romer's (1990) concepts about the knowledge diffusion process describe the spillover effects, which occur when innovations in one domain amplify overall productivity within the economy thereby fostering its maturity.

Trade and innovation in the light of global economic growth look quite impressive. Global trade, therefore, brings about more innovation; it creates bigger markets and facilitates the flow of knowledge. As a result, it leads the world to a higher level of economic growth.

The policy implications for stimulating innovation growth have been intensively discussed among the key actors and measures that are believed to be capable of playing that role include R&D investments, intellectual property protections, entrepreneurial-conducive environments and prioritizing education and skills building in a bid to make innovation to border economic growth. By basing their findings on government support for the exploration of frontier research and innovation-friendly regulation, the above studies also make it clear.

Innovation plays the economic role of the escalator, holding its own in the productivity scene and competing at the international level, while at the macro and micro levels, it is the driving force behind economic growth. The understanding of innovations' growth pathways and the creation of new policies that enhance and encourage the growth of the economy should remain the key factors that will promote development over the long term.

2.3. Innovation and education

The role of education in innovation would be approved through this scientific literature, and education would be seen as an integral prerequisite to innovation. A huge amount of researches prove that people with education have a sufficient inventory of know-how, knowledge of the area, and the ability to critically think through which they generate and apply new emerging ideas. The records often contain a positive relationship between a high education level and expanded innovations, not just at a personal level but also at a societal level as well. When learning of creativity, critical thinking skills and problem-solving abilities, education asserts an ever-increasing role in the generation of new ideas. The study points out that learning environments that entail experimenting, combine different disciplines and provide a warm and comprehending atmosphere as cornerstones for boosting innovative thinking among students and practitioners alike.

It should be pointed out, however, that highly educated institutions such as the higher education hubs and the research focal points are the ones that often impact tremendously and spark new innovations in various domains as discussed in Stephan's

(2010) paper. Besides, research by Acemoglu and Autor (2011), Carayannis and Campbell (2012), Goldin and Katz (2009), Hoxby (2000), and Lleras-Muney (2005) are the brightest examples showing that educational success levels are positively correlated to the innovativeness of the economy. A historically developed country/area with an advanced education system usually has better chances to innovate efficiently and register more patents for its new technologies, inventions and scientific discoveries.

Among these are innovations within the education field itself; such as changes in educational technologies, pedagogical techniques and ways of learning, all of which have the potential to revolutionize entirely all learning experiences and allow individuals to better acquire the right skill-sets that fit the innovations in their work environment. Agreed policies of education reform sequencing, transfer of STEM education, continuity drives of lifelong learning, and the partnership of academia and industry are, therefore, found to be essential in the creation and maintenance of an innovative society in which education brings in and stimulates innovation.

Understanding this complex link exactly, however, is a key that is sorely needed when designing policies that promote innovation as well as lifelong learning, fundamentally pushing economic growth and social development.

3. Methodology

3.1. Research area

The dataset utilized comprises cross-country observations spanning 56 countries from 2005 to 2021, sourced from the World Development Indicators database (http://data.worldbank.org/indicator). In this study, we analyze data from 56 countries globally, encompassing both developed and developing nations. The selection of countries was based on data availability. The variables encompass GDP growth rate, serving as an indicator of economic growth; RAD, employed as a proxy for research and development expenditure; PATENT, utilized as a proxy to represent the number of patent applications; and EDU, serving as a proxy to measure expenditure on education. These variables were chosen to investigate and understand potential correlations and relationships among economic growth, research and development spending, patent applications, and education expenditure across the selected countries during the specified timeframe.

3.2. Research model

In this research, we employ panel data encompassing observations from 56 countries to estimate the model. Panel data analysis allows for the utilization of data across multiple entities (such as countries) and time periods. The aggregated panel dataset comprises time series information for each member within the dataset, offering diverse estimation methods (Asteriou and Hall, 2007).

To investigate the intricate interrelationships between education, innovation, and economic growth across diverse countries, we employ a Cobb-Douglas production function where the Gross Domestic Product (GDP) relies on human capital and innovation.

Transforming the model by taking logarithms results in the linearized form as follows:

$$GDP_{it} = \alpha_1 + \alpha_2 RAD_{it} + \alpha_3 PATENT_{it} + \alpha_4 EDU_{it} + \varepsilon_t$$

where, the subscript $i = 1, 2, \ldots, N$ denotes the country (in this study, encompassing 56 countries), $t = 1, 2, \ldots, T$ denotes the time period (within the time frame of 2005–2021), and ε stands for the error term.

In this model, GDP represents the GDP growth rate. It indicates the percentage change in Gross Domestic Product (GDP) over a specific period, usually measured annually. This metric serves as a crucial indicator of economic performance and reflects the rate at which a country's economy is expanding or contracting. A positive GDP growth rate signifies economic growth, indicating that the economy has expanded compared to the previous period. Conversely, a negative GDP growth rate indicates economic contraction, suggesting a decrease in economic output. The GDP growth rate is a fundamental measure used by economists, policymakers, and investors to assess the health and trajectory of a country's economy.

RAD indicates the percentage of research and development expenditure as a proportion of GDP. It serves as a crucial indicator representing the allocation of resources dedicated to research and development activities concerning the overall economic output of a nation. This metric measures the extent to which a country invests in innovation and technological advancement relative to its economic size, offering insights into the commitment to fostering innovation and its importance in the national economy. A higher RAD value signifies a more substantial commitment to research and development relative to the nation's economic output, often indicating a greater emphasis on innovation and technological progress as drivers of economic growth and competitiveness.

PATENT signifies the number of patent applications. It represents the count or volume of applications filed with relevant patent offices seeking protection for new inventions, designs, or technological innovations. This metric is a quantitative measure indicating the level of innovative activities within a country or organization. A higher number of patent applications typically suggests increased innovation and inventive activity, reflecting a commitment to developing new technologies, products, or processes. Patent applications serve as an essential indicator for measuring and comparing innovation levels among different entities, providing insights into the innovative capacity and potential technological advancements within a specific jurisdiction or industry sector.

EDU represents expenditure on education as a percentage of government expenditure. It indicates the proportion of a country's overall government spending allocated specifically to the education sector. This metric provides insight into the prioritization of education within the government's budgetary allocation. A higher percentage for EDU signifies a more significant share of government funds dedicated to education, indicating a greater emphasis on investing in educational programs, infrastructure, resources, and initiatives. This allocation ratio is crucial in assessing the level of commitment and priority given to educational development within a nation, reflecting efforts aimed at improving educational access, quality, and outcomes for its citizens.

This model aims to explore and quantify the relationships among economic output, research and development investment, patent applications, and education spending across the specified countries and time periods.

3.3. Procedure of conducting research

To ascertain a potential long-term relationship between the variables, a cointegration test is applied, necessitating an assessment of whether all the variables are stationary at the level. If the series are non-stationary at the initial level, they undergo differencing to achieve stationary positions. Once the series become stationary at the first difference level, a cointegration test is performed, following the principles outlined by Dickey and Fuller (1981) and Phillips and Perron (1988). The initial step involves conducting the panel unit root test, using methodologies proposed by Im et al. (2003) and Levin et al. (2002), which are both founded on the Augmented Dickey-Fuller principle.

The study utilizes the LLC and IPS unit root tests developed on the precepts of the Augmented Dickey-Fuller (ADF) method to check for the stationarity/non-stationarity nature of the variables. The cointegration test is performed beforehand to check the possible long-term and rate of equilibrium between the variables in the hypothesized model which is based on the theory advanced by Granger (1969) and then explained and developed further by Engle and Granger (1987).

The study applies panel cointegration tests to the case of panel data to figure out the short-term and long-term interrelationships using Kao and Chiang (2000), Kao (1999) and Pedroni (2004). Specifically, the univariate heterogeneous panel statistic based upon ADF by Pedroni (1999, 2004) and the group mean panel statistics from the same author are applied to run-tests alongside the original Dickey-Fuller (1981) and augmented Dickey-Fuller tests by Kao That makes for a comprehensive investigation of cointegration that comes about during the estimation process.

The introduction of advanced techniques such as Panel Dynamic OLS (DOLS), Fully Modified OLS (FMOLS) and Canonical Cointegrating Regression (CCR) is used to assess the weak sides of OLS estimators while carrying out panel cointegration testing. These estimators (Stock and Watson, 1993) take into account such problems as endogeneity and serial correlation. They also provide an efficient estimate of the long-run equilibrium relationships. Through DOLS, FMOLS and CCR applications, we are embraced by a thorough exploration of the complex relationships between the variables contingent on countries over a certain period.

To sum up, this paper employs the newly recognized techniques for cross-country panel data like advanced unit roots and co-integration tests alongside dynamic panel estimators, in both the short and the long run, to examine the relationships between the variables of interest in an econometric framework that is solid and grounded in literature. The approach we are choosing to accomplish this is to provide the enabling platform for understanding how economic and policy insights could be derived from the data.

4. Research results

4.1. Unit root tests

Based on the outcomes obtained from conducting unit root tests, several conclusions emerge (**Table 1**). Notably, none of the statistics reveal significance at the 1% level for all variables except GDP. However, upon differentiating the data into the first degree, a significant observation surfaces: All variables exhibit stationarity. Consequently, it is established that all series possess an order of integration of one. These findings prompt a deliberate exploration to assess the existence or absence of a long-term relationship among these variables by employing cointegration testing methodologies.

Table 1. Panel unit root tests.

Variables	Level		First difference	
	***T*-Statistics**	***p*-value**	***T*-Statistics**	***p*-value**
GDP	−9.8991	0.0000	−9.8389	0.0000
RAD	−2.0429	0.0205	−12.2467	0.0000
PATENT	−1.0087	0.1566	−11.8579	0.0000
EDU	−2.5852	0.0049	−10.9029	0.0000

Source: Author's estimation from Stata 15.

4.2. Cointegration tests

Table 2 displays the outcomes derived from the Kao (1999) panel cointegration test. The test results dismiss the null hypothesis indicating no cointegration for the economic growth and associated variables at a 1% significance level. Consequently, it signifies the presence of cointegration among these variables.

It is evident across all panel datasets that a long-term relationship exists among economic growth, research and development expenditure, patent applications, and education expenditure within our continental panel. Given the established cointegration between economic growth and the remaining variables in our model, we proceed to estimate the equation model using the DOLS, FMOLS, and CCR methods.

Table 2. Kao panel cointegration tests.

	***T*-statistics**	***p*-value**
Modified Dickey-Fuller *t*	−15.7141	0.0000
Dickey-Fuller *t*	−17.8998	0.0000

Source: Author's estimation from Stata 15.

4.3. Estimation results

After confirming the existence of a cointegration relationship between the series, we have to move to the estimation of the long-term relationship (**Table 3**). There are different available estimators to estimate cointegration panel data, such as fully modified OLS (FMOLS) estimators, dynamic OLS (DOLS), and canonical cointegrating regression (CCR).

For the variable RAD, all three estimation methods—DOLS, FMOLS, and CCR—indicate a statistically significant negative effect at the 1% significance level. This suggests a substantial and negative relationship between RAD and GDP growth rate across these estimation methodologies.

Table 3. Estimation results using DOLS, FMOLS, and CCR.

Variables	DOLS	FMOLS	CCR
RAD	−0.4483717***	−0.6553262***	−0.6554658***
PATENT	3.59×10^{-6}***	3.91×10^{-6}***	3.91×10^{-6}***
EDU	0.1348367***	0.1452872***	0.1453549***
Observation	952	952	952
R-square	0.892078	0.293689	0.082497

***, **, * represent significant level of 1%, 5%, 10%. Source: Author's estimation from Stata 15.

Regarding PATENT, the results are consistent among the three methods, indicating a significant positive impact at the 1% significance level. This implies a positive association between PATENT and GDP growth rate across all estimation techniques employed.

Similarly, for the variable EDU, the estimations from DOLS, FMOLS, and CCR display a significant positive effect at the 1% significance level. This signifies a robust and positive relationship between EDU and the dependent variable across these estimation models.

5. Discussion

Our study aimed to discuss the topic of the association between education, innovation, and economic development with the help of panel data methodology. The key finding demonstrated a strong long-run relationship between GDP growth rate, research and development expenditure per capita (RAD), patent application number per capita (PATENT), and education expenditure.

The outcomes of the unit root and co-integration tests indicate the variables' stationarity of the first order and cointegrated in the long term in **Tables 1** and **2**. The empirical models of both STLST and the other methods always reveal a string of negative associations between RAD and economic growth at the macro level in **Table 3**. This move, on the contrary, disagrees with Goel et al.'s (2008) and Wang's (2007) study which revealed a positive and significant relationship between R&D spending and the growth of the economy. Hence, it seems possible that poor nations could be deficient in their absorptive capacity in the sense that they cannot make good use of R&D investments to move the economy forward with productive and innovative results.

Though education spending (EDU) is more strongly correlated with the GDP growth rate (PATENT) than several patents, the latter exhibits a statistically significant positive relationship with GDP growth rate (EDU) in **Table 3**. Moreover, the results cast light on Jalles's (2010) and Baldacci et al.'s (2008) findings showing that the accumulation of human capital requirements is crucial for long-term economic growth. With each nation spending to build a workforce with highly valued skills and know-how, the consequence of this leads to technological upgrading, productivity surges and steady economic growth (Fu et al., 2011).

The study involves important lessons that the policy-makers and governments would find useful in addressing issues that bar economic growth. Shafting money into R&D, indeed, could yield a good future. Yet, developing countries have to prioritize the need for human capital and skill development before the actual plan. Besides, it is reasonable to expect a learning ecosystem and educational infrastructure to have a positive influence on innovations therefore over time. Nevertheless, the study provides a limited view of the picture due to the intrinsic characteristics of several factors that contribute to developing a methodology to measure innovations. The next step will be to employ a mixed methods approach integrating both qualitative survey designs with more comprehensive empirical data. Such an approach will allow for a better perspective on the situation. Further on, the researchers could focus on country-specific and regional trends as this might help to find local solutions and issues.

6. Conclusion and recommendation

In the contemporary pursuit of a competitive economy, emphasis on crucial elements such as human capital, knowledge, and innovation remains paramount. Within the context of a knowledge-driven economy, education stands as the singular pathway toward skill development and competence enhancement, fostering competitiveness and long-term state advancement.

This study meticulously delved into the correlation between higher education, innovation, and economic growth across 56 countries during the 2005–2021 period, utilizing the DOLS, FMOLS, and CCR methods. The findings underscored that the quality enhancement of higher education significantly impacts economic growth, primarily through its emphasis on fostering innovation. This substantiates the criticality of integrating innovation into the higher education system, thereby contributing to superior economic growth outcomes. Notably, amidst the considered macroeconomic variables, education emerges as the most statistically significant in its correlation with other macroeconomic factors and exhibits a substantial link with economic growth. This holds true for both developing and developed nations, affirming the pivotal role of education quality in influencing economic growth.

Education expenditure and the number of patent applications exhibit a positive correlation with GDP growth, underscoring the multifaceted nature of factors contributing to economic growth. Investments in education and innovation through patents play pivotal roles in fostering economic advancement.

Conversely, research and development (R&D) expenditure demonstrates a negative influence on the GDP growth rate. Understanding this unexpected correlation warrants consideration of various factors. Firstly, the time lag involved in R&D investments demands patience as tangible outcomes, like innovative technologies or products contributing directly to economic growth, take time to materialize. Consequently, heavy resource allocation to R&D may not immediately manifest observable economic expansion, leading to a short-term negative correlation. Secondly, misallocation or inefficient utilization of R&D funds towards projects lacking economic value can transiently impede economic growth. Thirdly, the substantial costs associated with R&D, encompassing equipment, skilled personnel, and experimentation, may temporarily outweigh immediate benefits, impacting short-term economic output. Additionally, R&D initiatives sometimes result in disruptive innovations that initially disrupt existing industries before fostering new opportunities, causing short-term disruptions before contributing substantially to economic growth.

Finally, the allocation of R&D spending across sectors can influence its impact on GDP growth rate; concentration in slower-growing sectors might yield an apparent negative effect on overall GDP growth.

Leveraging these insights yields several recommendations. Firstly, it's essential to reassess R&D strategies, emphasizing efficiency, targeted innovation, or realignment toward research areas aligned with economic growth objectives. Secondly, prioritizing increased investments in education is crucial, aiming to enhance infrastructure, elevate educational quality, and broaden access across various demographics. Additionally, fostering innovation and patenting culture through policies supporting patent applications and fostering collaboration among academia, industry, and research institutions is vital. Lastly, adopting an integrated policy approach that balances R&D efficiency, education quality, accessibility, and innovation promotion is pivotal. Coordinated policies addressing these interconnected aspects holistically hold the potential to generate significant and sustainable improvements in GDP growth rates.

By implementing these recommendations while acknowledging the nuanced relationships between R&D, education, patents, and GDP growth, governments and organizations can potentially augment economic growth trajectories, fostering an innovation-driven, knowledge-based economy.

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