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AI Innovation and Economics Growth: A Global Evidence

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Abstract

This research investigates the impact of artificial intelligence on economic growth, focusing on how AI-related activities such as scholarly publications, patent filings, and national AI strategies influence GDP across different national contexts. The study utilizes a comprehensive dataset from 2010 to 2023, covering 141 countries, and employs the SGMM to analyze the economic impacts of AI. Additionally, the study incorporates a Random Forest algorithm to assess the importance of various AI-related features, providing a nuanced understanding of which aspects of AI are most predictive of economic outcomes. This dual-methodology approach allows for robust analysis by addressing potential endogeneities with SGMM and validating feature significance with Random Forest. This ensures a thorough examination of AI's contributions to economic growth. The SGMM analysis confirms that AI innovations significantly boost economic output, particularly in countries with robust AI strategies and advanced infrastructure. Complementing this, Random Forest analysis highlights that patents per million and comprehensive national AI strategies are crucial in predicting economic growth. These features are key drivers, indicating that dense innovation environments and strategic planning are essential for maximizing AI's economic benefits. The study suggests that to leverage AI's full economic potential, policymakers and business leaders should develop comprehensive AI strategies and foster environments conducive to AI integration. This research contributes unique insights into the quantitative effects of AI on economic growth, highlighting the role of national policies and infrastructure in enhancing AI's economic impact. It offers a nuanced understanding of AI's potential as a driver of sustainable economic development.

Keywords: Artificial Intelligence, Economic Growth, SGMM, Random Forest.

1 Introduction

Integrating artificial intelligence (AI) into various sectors represents a technological shift and a transformative economic force that promises to redefine how industries operate and compete. This evolution of AI extends beyond mere automation, influencing broad aspects of economic development such as labor markets, education systems, and global trade dynamics. The potential for AI to enhance productivity and foster innovation opens up new avenues for economic expansion and raises important considerations for competitiveness and inequality. As AI technologies evolve, they weave increasingly complex interactions within economic structures worldwide, capturing the attention of academics, policymakers, and industry leaders who seek to understand and leverage these changes.

In recent years, the theoretical discourse around AI's economic implications has expanded, yet empirical studies remain disparate, often yielding mixed findings (Abdulov, 2020; Bonsay et al., 2021; Lu, 2021; Trammell & Korinek, 2023; Vijayakumar, 2021; Zhao et al., 2022; Zuo & Ai, 2011). This study will bridge this gap by comprehensively analyzing how AI innovations correlate with economic performance across various national contexts. Drawing on extensive data spanning from 2010 to 2023 and encompassing a diverse range of economies, this research employs the System Generalized Method of Moments (SGMM) to offer nuanced insights into the specific economic contributions of distinct AI activities, such as scholarly publications, patent filings, and national AI strategies.

The exploration of AI's economic impact is particularly pertinent given the rapid pace of AI development and its penetrative capability into all sectors of the economy (Chen et al., 2016; Qian et al., 2023). The dual nature of AI as both a product and a process innovation allows it to drive change through new products and services and the transformation of production processes and business models (Hatzius, 2023; Vyshnevskyi et al., 2019). This dual capability of AI necessitates a comprehensive examination to distinguish between its short-term disruptions and long-term benefits to economic structures.

Moreover, the research engages with existing economic theories that frame the role of technological innovation in growth, such as those proposed by Schumpeter regarding creative destruction. It extends into modern interpretations of endogenous growth theories, emphasizing technology and knowledge's importance. By situating AI within these theoretical frameworks, the study investigates how AI contributes to economic outputs and reshapes economic inputs, labor dynamics, and capital formation.

This paper aims to provide a holistic understanding of how AI innovations influence economic growth by dissecting the channels through which AI transforms traditional economic paradigms and identifying these transformations' policy implications. It seeks to contribute to the body of knowledge that assists policymakers, business leaders, and academics in making informed decisions that harness AI's potential for promoting sustainable economic growth while mitigating the risks associated with its widespread integration.

2 Literature Review

2.1. Background theories

The relationship between AI innovation and economic growth is a dynamic and evolving area of research that draws on several theoretical foundations. Understanding the interplay of these theories helps illuminate how AI as a technological innovation can spur economic development and transformation across global economies.

Economic growth theories, particularly those proposed by Schumpeter and modern endogenous theorists like Romer (1990) and Lucas Jr (1988), provide a multifaceted understanding of the dynamics between innovation and economic development. Schumpeter's concept of "creative destruction" resonates strongly in the context of AI innovation, as AI often catalyzes profound changes across industries, disrupting existing business models and labor markets while fostering new forms of productivity and economic activity (Aghion & Howitt, 1990). This disruption is not merely destructive but generative, creating opportunities for growth and development that did not previously exist.

Similarly, Romer (1990) and Lucas Jr (1988) endogenous growth theory enhances this view by emphasizing the role of knowledge and technology as engines of growth. AI, at the frontier of technological and knowledge advancement, exemplifies how investment in technology propels innovation and amplifies economic outputs through improved efficiencies and capabilities. These theories collectively suggest that the path to sustained economic growth hinges significantly on how effectively an economy can leverage AI within its innovation ecosystem.

Adding to this, the diffusion of innovations theory Rogers (2003) explores how the spread of AI technologies across sectors influences the pace and scale of economic growth. This theory highlights the importance of adoption rates, which network effects, the regulatory environment, and the existing technological infrastructure can influence. The faster and more widely AI is adopted, the greater its impact on economic productivity and growth. Furthermore, the systems of innovation framework Freeman (1987) and Lundvall (1992) tie these individual aspects into a cohesive whole by focusing on the ecosystem that supports or hinders innovation. It emphasizes the need for solid interactions between government, academia, and industry to cultivate an environment that can effectively harness the economic potential of AI. This systemic view acknowledges that the benefits of AI are maximized in a conducive policy environment that supports R&D, facilitates technology transfer, and promotes AI education and training.

Despite the rich theoretical frameworks available, there remains a gap in understanding the specific mechanisms through which AI innovation translates into economic growth within different institutional and economic contexts. Most existing studies focus on the generalized impacts of technology on growth without delving into the unique attributes of AI, such as its potential for self-learning and its implications for labor markets and productivity in various industries. Furthermore, the differential impact of AI across developing versus developed economies, moderated by factors such as technology diffusion rates and innovation system efficiencies, requires more detailed investigation.

These theories collectively support exploring how AI innovation impacts economic growth by providing multiple lenses to view this relationship. Schumpeterian and endogenous growth theories emphasize the transformative potential of AI on economic structures and the importance of ongoing innovation (Schumpeter, 2021). In contrast, technology diffusion and innovation systems theories stress the importance of broad and effective adoption and supportive policies and interactions within the ecosystem. Examining AI innovation through these theoretical frameworks allows for a comprehensive analysis of its economic impacts, guiding policymakers and business leaders in harnessing AI's potential for sustainable growth.

2.2. Empirical studies

In examining the empirical evidence of AI’s impact on economic growth and innovation, the literature reveals distinct thematic clusters that provide a nuanced view of how artificial intelligence integrates with and influences various economic sectors and regions.

One prominent theme is the overarching impact of AI on economic growth and innovation processes, as discussed by Gonzales (2023), Furman and Seamans (2019), and Allam (2016). These studies explore AI as a General-Purpose Technology, with Gonzales (2023) highlighting its role in boosting productivity and economic growth across countries. Using panel data from 1970 to 2019 and employing methods such as fixed effects and GMM estimation, Gonzales (2023) identifies a significantly positive impact of AI patents on economic growth. Similarly, Furman and Seamans (2019) review various statistical indicators, including robotics shipments and AI start-ups, to argue that AI and robotics are poised to enhance productivity growth. However, they also note the potential short-term disruptions to labor markets. Allam (2016) provides a practical perspective by surveying managers across multiple sectors, finding that AI’s role is crucial in reorganizing business processes and innovation activities. Despite their shared optimism about

AI's potential, these studies suggest the necessity for nuanced policy interventions to mitigate the adverse labor market effects highlighted by Furman and Seamans (2019).

Another significant cluster focuses on the sectoral and regional divergence in the adoption and impact of AI innovations. Grashof and Kopka (2023) and Kitsara (2022) offer insights into how AI's benefits are unevenly distributed. Grashof and Kopka (2023) investigate the differential impacts of AI on SMEs versus large firms in Europe, revealing that while AI applications foster innovation in large firms, AI techniques can be particularly beneficial for SMEs. This contrast highlights the varying capacities of firm sizes to leverage AI for radical innovations. Kitsara (2022) addresses the AI divide from a geographic perspective, emphasizing disparities in AI access and utilization between industrialized and developing regions and the implications for economic growth and the digital divide. Both studies underscore the importance of tailored approaches in technology policy to accommodate diverse organizational and regional contexts.

Lastly, the role of policy frameworks in enabling AI-driven economic growth is critically examined by Udvari and Ampah (2018) and Kim and Choi (2019). Udvari and Ampah (2018) assess the effectiveness of aid for innovation in Sub-Saharan Africa, using statistical models to argue that targeted innovation aid significantly enhances growth and innovation capacity. Conversely, Kim and Choi (2019) discuss South Korea's economic policies to foster innovation through the Innovative Platform Programme, suggesting that a well-conceived policy framework is essential for harnessing the economic benefits of AI. Both studies suggest that supportive policies are crucial for maximizing the economic outputs from AI, albeit noting the challenges in policy implementation and the potential for unintended economic consequences.

These clusters of literature reveal a consensus on AI's potential to drive economic growth and innovation. They also highlight critical disparities in how its benefits are realized across different sectors and regions. The mixed effects on labor markets, the importance of policy support, and the uneven distribution of AI capabilities underscore the need for ongoing research to address these challenges. As AI continues to evolve, further empirical research is necessary to refine our understanding of its economic impacts and to develop more effective policies that harness its full potential while mitigating its risks.

The empirical landscape surrounding AI innovation is marked by several gaps, particularly in the longitudinal analysis of AI's effects across different economic frameworks. While studies such as Gonzales (2023) provide preliminary insights into the benefits of AI, there remains a substantial deficiency in ongoing research that could systematically track how modern AI technologies influence diverse economies over extended periods. This gap is critical in light of endogenous growth theory, which underscores the prolonged impact of technological advancements on economic growth (Romer, 1990). There is a clear need for comprehensive long-term studies that explore how emerging AI technologies continue to shape economic structures and processes over time, offering insights that could greatly enhance our understanding of AI's transformative potential across various global contexts.

Additionally, the impact of AI on labor markets in developing economies is notably underexplored. The bulk of current research predominantly concentrates on developed countries, often overlooking the unique economic and social challenges developing regions face. This oversight is significant as the diffusion of AI in these economies and its socio-economic effects are less understood, yet critically important. Effective application of technology diffusion theory requires a deep understanding of how AI is adopted and its subsequent impact in these diverse contexts. Given the discussion surrounding the impact of artificial intelligence on economic structures and the theoretical backing from both endogenous growth theory and empirical studies suggesting a positive link between technological advancements and economic performance, a pertinent hypothesis for this research is as follows:

Hypothesis 1: The integration of AI innovations positively correlates with the acceleration of economic growth.

This hypothesis posits that as AI technology becomes more integrated into the economy, there will be a measurable increase in economic growth indicators such as productivity, efficiency, and overall GDP growth. The expectation is that AI's capabilities to optimize operations, enhance decision-making, and automate processes will significantly contribute to economic expansion and development.

3 Methodology

3.1. Data

The dataset utilized in this research comprises secondary data gathered from two prominent international data repositories: Our World in Data (ourworldindata.org) and the World Bank's Data Bank (databank.worldbank.org). These sources are well-regarded for their extensive and reliable datasets on global development indicators, which are critical for analyses of economic growth and technology integration across countries.

- Period and Coverage: The data covers a period from 2010 to 2023, providing a contemporary view of the effects of artificial intelligence on economic outcomes. This timeframe allows for examining recent AI innovations and their impacts on various economic sectors across different regions.
- Country-Level Analysis: The dataset includes observations from 141 countries, encompassing a broad spectrum of economic development stages and regional contexts. This diverse sample enhances the generalizability of the study's findings, offering insights into both developed and developing economies.
- Observations and Data Cleaning: The total number of observations in the dataset is 2,968. In line with the study's methodology, any observations containing missing values were excluded from the analysis to maintain the integrity and accuracy of the results. This decision ensures that the subsequent analysis is based on complete cases, providing a solid foundation for robust statistical inference.
- Data Variables: While the specific variables collected from Our World in Data and the World Bank's Data Bank are not detailed here, they typically include metrics relevant to economic performance and technological innovation. These variables are critical for exploring the relationship between AI innovation and economic growth, as outlined in the study's hypothesis.

The dataset is cut off by 3%.

3.2. Empirical Models

This research aligns with the econometric approaches previously utilized by Wong et al. (2005), Kim and Lee (2015), He (2019), and Gonzales (2023). For estimating Equation (1) as outlined in the preceding section, the econometric model adheres to the following equation:

$$gdp\_growth_{it} = \beta_0 + \beta_1\, gdp\_growth_{i,\,t-1} + \beta_2 AI\_var_{it} + \beta_3 cap\_form_{it} + \beta_4 trade_{it} + \beta_5 pop\_lag\_city_{it} + \beta_6 national\_exp_{it} + \beta_7 adv\_eco_{it} + \beta_8 adv\_eco_{it} * AI\_var_{it} + \varepsilon \qquad (1)$$

In that,

- gdp_growth_{it}: GDP growth of country i at time t.
- $gdp\_growth_{i,\,t-1}$: GDP growth of country i at time t-1.
- AI_var_{it}: artificial intelligence variable, including the number of scholar publications related to AI, number of patent submissions, number of patent submissions on 1 million people, and national strategy on AI of country i at time t.
- cap_form_{it}: capital formation of country i at time t.

- $trade_{it}$: trade of country i at time t.
- $pop\_lag\_city_{it}$: population in lag city of country i at time t.
- $national\_exp_{it}$: national expense of country i at time t.
- adv_eco_{it}: advance economic of country I at time t, dummy variable (0 if the economy is not advanced, 1 if the economy is advanced).
- $\beta_0 \rightarrow \beta_8$: coefficient.
- ε: error term.

In this study, employing the System Generalized Method of Moments (SGMM) is crucial due to the dynamic nature of the economic model, which includes GDP growth lagging by one period. This approach effectively handles the inherent challenges of modeling how previous economic conditions influence future growth, a central theme when assessing the impact of AI innovation on economic performance. SGMM is particularly suited for addressing endogeneity issues common in models that incorporate AI-related variables, which are likely influenced by and simultaneously influence economic growth. By using internal instruments, specifically the lagged values of explanatory variables such as AI innovation, SGMM provides unbiased and consistent estimators, which align with previous studies such as He (2019) and Gonzales (2023).

Table 1: Variables measurement

Symbol	Measure	References	Data source
gdp_growth	GDP per capita growth (annual %)	Kim and Lee (2015); Fan and Liu (2021)	World Bank national accounts data, and OECD National Accounts data files.
schorlar_pub	Annual scholarly publications on artificial intelligence	Aghion et al. (2017); Gonzales (2023)	Center for Security and Emerging Technology
patent	Annual patent applications related to artificial intelligence	Fan and Liu (2021); Gonzales (2023)	Center for Security and Emerging Technology
patent_per1mil	Annual patent applications related to AI per million people	Aghion et al. (2017); Gonzales (2023)	Center for Security and Emerging Technology
national_str	National strategy on AI	Kim and Lee (2015); Fan and Liu (2021)	AI Index (2023)
cap_form	Gross capital formation (% of GDP)	Ulku (2004); Gonzales (2023)	World Bank national accounts data, and OECD National Accounts data files.
trade	Trade (% of GDP)	Kim and Lee (2015); Fan and Liu (2021)	World Bank national accounts data, and OECD National Accounts data files.
pop_lag_city	Population in the largest city (% of urban population)	Ulku (2004); Gonzales (2023)	United Nations, World Urbanization Prospects.
national_exp	Gross national expenditure (% of GDP)	Ulku (2004); Kim and Lee (2015)	World Bank national accounts data, and OECD National Accounts data files.

adv_eco	Advanced Economy (0 if the economy is not advanced, 1 if the economy is advanced).	Gonzales (2023)	World Economic Outlook by IMF

Source: By author

Table 1 provides an overview of the variables used to explore the impact of artificial intelligence innovation on economic growth. It effectively combines macroeconomic indicators such as GDP per capita growth, gross capital formation, trade, and national expenditure alongside specific AI-related metrics like scholarly publications, patent applications, and national artificial intelligence strategies. These variables are integral to assessing both the broad economic effects and the direct contributions of artificial intelligence within various contexts. Additionally, including demographic and strategic variables like population in the largest city and advanced economy status enriches the analysis, allowing for a nuanced exploration of how artificial intelligence impacts differ across varying economic and urban settings. This blend of economic and AI-specific variables is essential for a holistic understanding of the dynamics between artificial intelligence innovation and economic development.

After the econometric analysis using the SGMM, the study also employs a Random Forest algorithm to extract feature importance, providing additional insights into the predictive power of various AI-related variables. This machine learning approach helps identify which features are most influential in driving economic growth, offering a robust complement to the traditional econometric methods. By analyzing the variable importance generated by the Random Forest, the study can pinpoint the most effective elements within the broader AI framework, thus refining the understanding of AI's impact on economic dynamics. This methodology not only reinforces the findings from the SGMM but also adds a layer of granularity to the analysis, highlighting the nuanced contributions of different AI innovations to economic development.

4 Results & Discussion

4.1. Descriptive analysis

Table 2 offers a statistical summary of the variables collected to investigate the influence of AI on economic growth. It spans 2,968 observations, reflecting data across various countries from 2010 to 2023. Key variables include GDP per capita growth, scholarly publications on artificial intelligence, patent applications related to artificial intelligence, patents per million people, national artificial intelligence strategy, gross capital formation, trade percentage of GDP, population percentage in the largest city, and national expenditure. A closer examination of the data reveals some critical insights and significant variances among the variables. The average annual GDP growth stands at 2.2%, with a substantial standard deviation of 5.2%, indicating notable fluctuations in economic performance across the dataset. The skewness and kurtosis values suggest that GDP growth experiences extreme values, which could indicate financial volatility in certain periods or regions.

Table 2: Descriptive summary for variables.

	gdp_ growth	**schorlar_ pub**	**patent**	**patent_ per1mil**	**national_ str**	**cap_form**	**trade**	**pop_lag_city**	**national_exp**
count	2968	2968	2968	2968	2968	2968	2968	2968	2968
mean	2.2	1130.9	102.8	0.5	0	23.7	82.6	32.9	102.4
std	5.2	7423.7	1655	4.9	0.2	7.7	50.8	18	15.2
min	-55.2	0	0	0	0	-15.9	4.1	3.1	40.1
25%	0.3	0	0	0	0	19.3	51.8	21.1	95.8
50%	2.3	0	0	0	0	23	71.3	30	101.9
75%	4.5	162.5	0	0	0	27.4	99.4	41.6	110.2
max	97	177078	64407	158.1	1	76.8	442.6	100	201
skew	0.9	15.3	28.6	21	4.3	0.8	3	1.3	0
kurtosis	52.1	286.6	959.7	562.2	16.1	2.9	14.1	2.5	2.4

Source: By author

Besides, scholarly publications on artificial intelligence and patent applications exhibit a highly skewed distribution, with mean values of 1130.9 and 102.8, respectively, but most of the data is concentrated near the lower range, as evident from the median values being zero. This skewness, coupled with extremely high kurtosis values, suggests that a few countries have very high counts, potentially dominating the artificial intelligence landscape, while most countries have few or no activities recorded in these areas. Such disparity highlights the concentration of artificial intelligence innovation and research in select global hotspots.

Furthermore, the 'patent per million' and 'national strategy' variables further emphasize this concentration, with most observations showing zeros in these categories, indicating limited engagement with artificial intelligence at a per capita level and a lack of formal artificial intelligence strategies in many countries. Trade as a percentage of GDP and gross capital formation indicate more uniform distribution across the countries but still show right-skewness, suggesting that while trade and investment are common, high values are less frequent but significantly impact the economic landscape when they occur.

Overall, the data paints a picture of an uneven global distribution in artificial intelligence innovation's impact on economic growth, with significant outliers and variances suggesting both opportunities for deep dives into specific high-impact regions and the need for strategies to elevate artificial intelligence engagement in underrepresented areas. This variance and the extremes noted in skewness and kurtosis across almost all variables suggest that while artificial intelligence can impact economic metrics significantly, its benefits and development are currently highly concentrated.

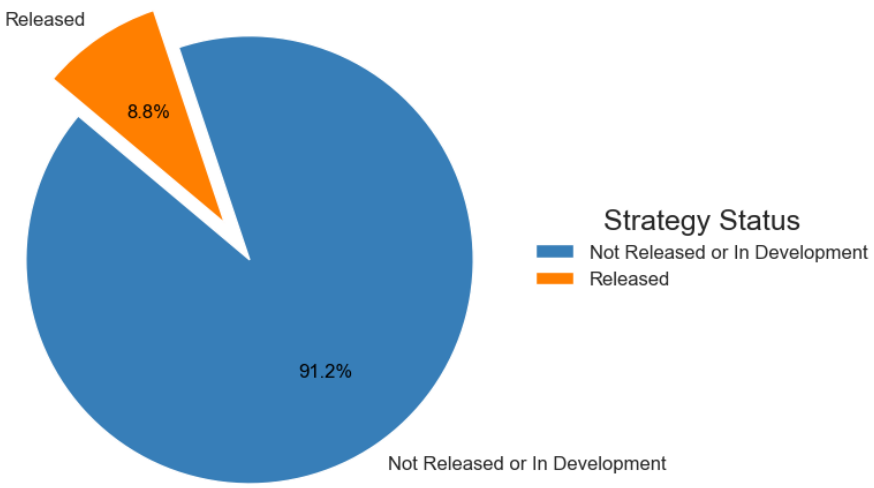

Figure 1: National artificial intelligence strategies release status

Source: By authors

Figure 1 presents the current status of artificial intelligence strategies across various countries, indicating whether these strategies have been officially released or are still under development or not released. It shows that a vast majority, 91.2%, of countries have not yet released their artificial intelligence strategies, suggesting that these are either in the development phase or have not been initiated. In contrast, only a small portion, 8.8%, of countries have completed and released their artificial intelligence strategies. This significant difference between the two groups could be indicative of varying stages of readiness and commitment to integrating artificial intelligence within national frameworks. The chart highlights a global trend where most countries are still in the preliminary stages of adopting artificial intelligence at a strategic level. This suggests a cautious approach towards artificial intelligence deployment, likely influenced by the complexities involved in establishing comprehensive artificial intelligence strategies that effectively integrate technological, ethical, and regulatory considerations.

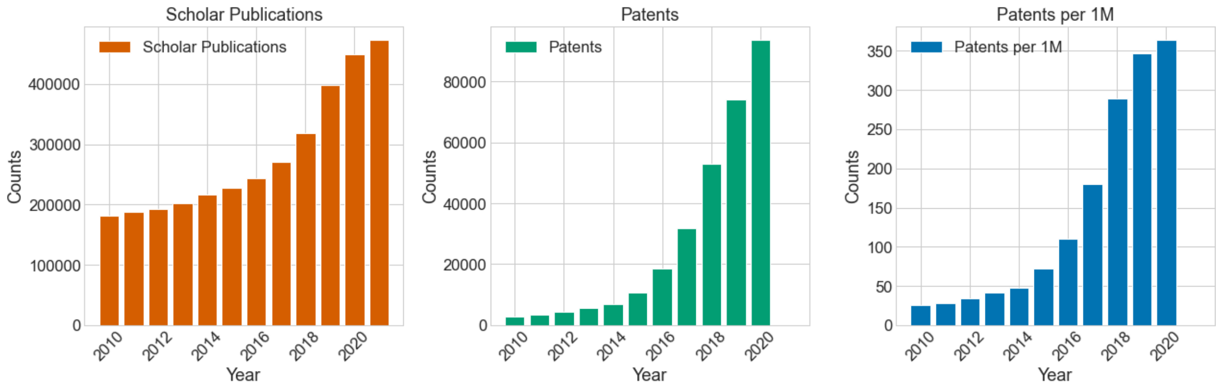

Figure 2: Number of scholar publications, patents, and patents per 1 million people over years

Source: By authors

Figure 2 highlights a significant and consistent growth in AI innovation over the decade from 2010 to 2020. The first graph shows a steady increase in AI-related scholarly publications, which have grown from approximately 150,000 in 2010 to over 450,000 in 2020. This trend indicates a growing interest and investment in AI research within the academic community, reflecting AI technologies' rapid advancements and expanding applications across various fields. The second graph illustrates the number of AI-related patents issued each year. This metric has also dramatically risen, starting from fewer than 10,000 patents in 2010 and reaching over 80,000 by 2020. The surge in patent counts signifies increased innovative activities and a heightened emphasis on protecting intellectual property in the AI domain. This trend underscores the competitive nature of AI development and the strategic importance of securing technological advancements through patents. The third graph, which depicts the number of AI-related patents per million people, further reinforces the notion of widespread and growing innovation in AI. This metric has increased from approximately 10 patents per million people in 2010 to around 350 patents per million people in 2020. This significant rise suggests that AI innovation is growing in absolute terms and becoming more prevalent relative to the global population. The increase in patents per capita highlights the diffusion of AI technologies and their increasing penetration into various sectors and regions worldwide.

The data underscores AI innovation's rapid and widespread growth over the past decade. The significant increases in scholarly publications, patent counts, and patents per capita reflect the dynamic and competitive nature of the AI landscape, driven by both academic research and industrial development. This trend points to the crucial role of AI in driving economic growth and technological progress on a global scale.

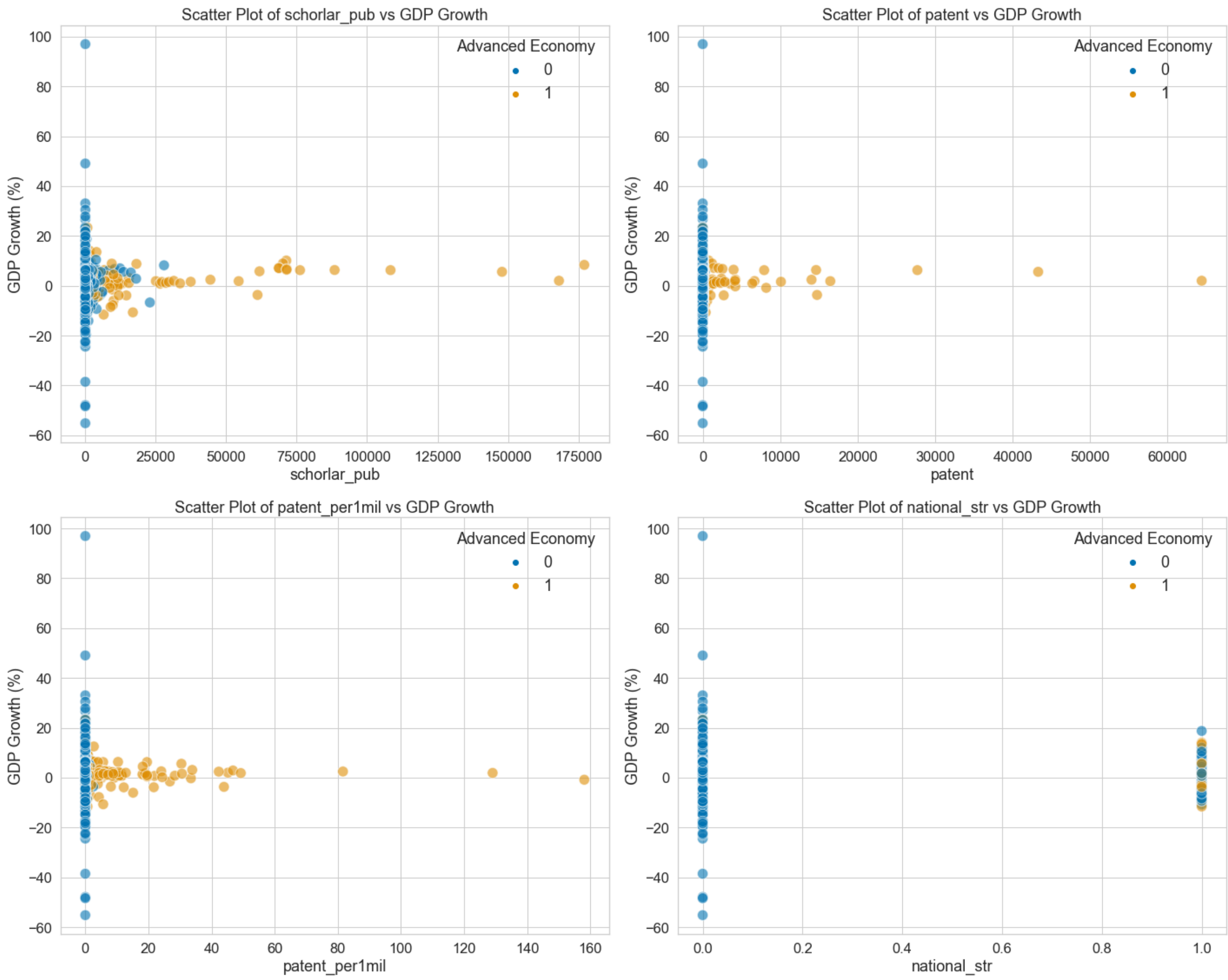

Figure 3: Scatter plot between GDP growth, number of scholar publications, patents, patents per 1 million people, and national strategies on AI

Source: By authors

Figure 3 consists of four scatter plots, each comparing GDP growth with different intellectual and strategic output metrics across countries. These metrics are the number of scholarly publications, patents per 1 million people, and a national strategy score. Each plot differentiates countries as advanced economies (marked as '1') or non-advanced (marked as '0').

The top left scatter plot shows scholarly publications plotted against GDP growth. Here, data points are densely packed at lower publication counts across advanced and other economies, showing no clear correlation between high scholarly output and GDP growth. While some advanced economies with relatively high publication numbers show moderate GDP growth, similar growth rates are observed in some non-advanced economies with fewer publications, indicating the influence of other economic factors beyond academic output.

The top right scatter plot presents the total number of patents filed against GDP growth. Similar to scholarly publications, most data points cluster at the lower end of the patent count, and there is a significant overlap in the GDP growth rates among countries with low to moderate patent outputs. A few outliers with high patent counts do not exhibit substantially different GDP growth, suggesting that the sheer number of patents is not a straightforward indicator of economic performance.

The bottom left scatter plot examines patents per 1 million people against GDP growth. This plot reveals a slightly more dispersed set of data points, particularly among advanced economies, which show a wider range of patents per capita. However, like the previous metrics, there is no evident pattern linking a higher density of patents per capita to superior GDP growth, highlighting that other economic variables likely play more critical roles in determining national economic performance.

The bottom right scatter plot correlates national strategy scores with GDP growth. National strategy scores, ranging from 0 to 1, represent how structured and developed a country's policies and frameworks are about innovation and technology. Data points are spread across the full range of strategy scores without showing a direct relationship with GDP growth. This distribution suggests that while having a coherent national strategy is presumably beneficial, it does not linearly translate into immediate economic growth.

These scatter plots suggest that higher intellectual outputs and well-defined strategic scores are not singular predictors of GDP growth. The apparent lack of a strong correlation in any of the metrics with GDP growth across advanced and other economies indicates the complex nature of economic development. Economic growth is likely influenced by a multifaceted array of factors including, but not limited to, economic policy, quality of governance, global economic conditions, and perhaps qualitative aspects of these intellectual and strategic outputs rather than their quantitative measures. The variability in GDP growth across similar ranges of scholarly publications, patents, and strategy scores emphasizes the importance of broader economic analyses and the consideration of diverse factors in understanding economic dynamics.

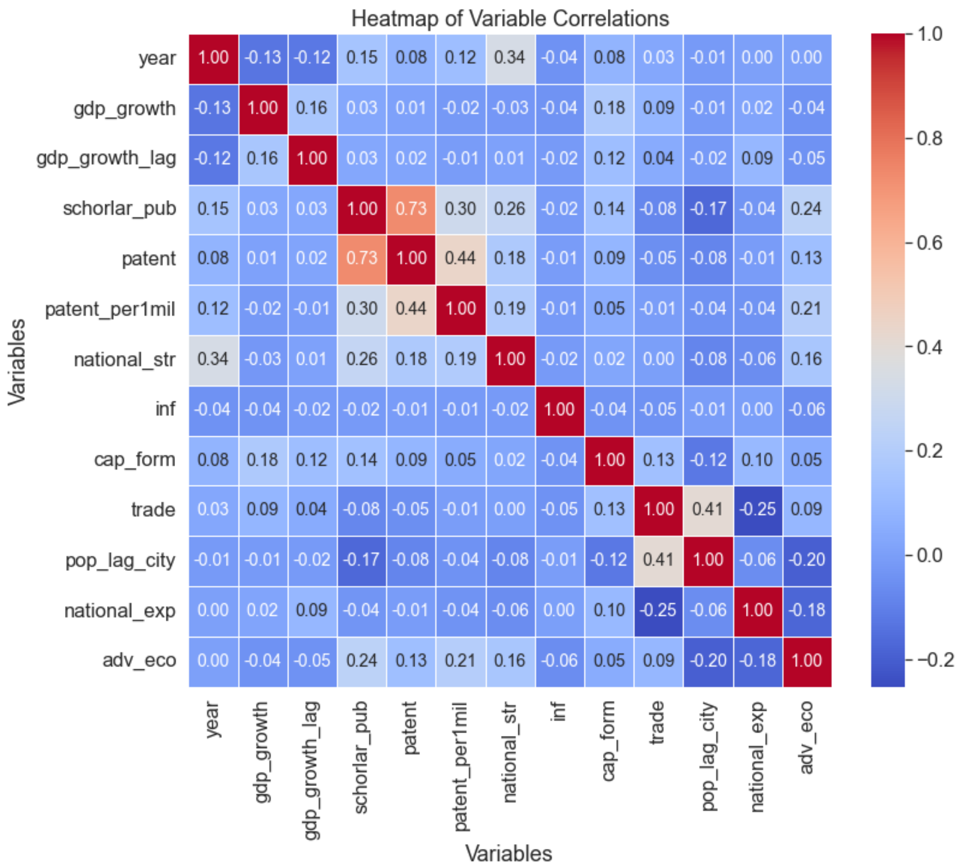

Figure 4: Correlation between variables

Source: by authors

The heatmap visually represents correlation coefficients between economic and policy-related variables, emphasizing the relationships between scholarly publications, patents, national strategy, and economic indicators such as GDP growth. A notable observation from the heatmap is the strong positive correlation of 0.73 between scholarly publications (scholar_pub) and patents (patent). This suggests a significant link between academic research output and the generation of new patents, implying that higher levels of research activity are associated with increased innovation, as measured by patent filings. Similarly, patents show a positive correlation of 0.44 with patents per million people (patent_per1mil), indicating that countries with higher overall patent filings also tend to have more patents per capita, showcasing a pervasive culture of innovation.

The national strategy score (national_str) also shows meaningful correlations, particularly a 0.34 with the variable year, reflecting a growing emphasis on strategic national planning over time. Additionally, it correlates with scholarly publications at 0.26, pointing to the potential role of strategic national frameworks in fostering or supporting academic and research activities. Interestingly, GDP growth (gdp_growth) exhibits very weak correlations with scholarly publications and patents, indicating that these factors do not directly and strongly influence immediate economic growth. This weak correlation may suggest that short-term economic performance is driven by variables not captured in this analysis, such as economic policies, market conditions, or other external economic factors.

In conclusion, the heatmap highlights the intricate relationships between intellectual outputs like research and patents and broader economic and strategic frameworks. While these intellectual activities are crucial for fostering innovation, their direct impact on short-term economic growth appears limited, suggesting a more complex interaction with other economic dynamics.

4.2. Empirical results

The regression results in **table 3** provide an insightful exploration into the role of AI-related variables and broader economic factors on GDP growth. The analysis highlights the significance of scholarly publications on AI (schorlar_pub), which positively influences GDP growth, with a coefficient significant at the 5% level. This indicates that academic endeavors in AI enhance the knowledge base and translate into tangible economic advancements. The interaction between scholarly publications and advanced economic conditions (adv_eco*schorlar_pub) further underscores this relationship, showing significance at the 10% level, suggesting that in more developed economies, the integration of academic research into the market is more efficient, leading to greater economic outputs.

Table 3: Regression results

AI variable	schorlar_pub	patent	patent_per1mil	national_str
const	1.967***	1.968***	1.968***	1.968***
gdp_growth_lag	1.277***	1.278***	1.277***	1.277***
cap_form	1.058***	1.060***	1.059***	1.057***
trade	0.008	0.006	0.009	0.014
pop_lag_city	0.107	0.112	0.112	0.106
national_exp	-0.295***	-0.294***	-0.296***	-0.297***
inf	-0.474***	-0,474***	-0.474***	-0.474***
adv_eco	0.001*	0.001*	0.042*	0.007*

schorlar_pub	0.223**			
adv_eco*schorlar_pub	0.227*			
Patent		0.123*		
adv_eco*patent		0.079*		
patent_per1mil			1.050*	
adv_eco*patent_per1mil			0.940*	
national_str				0.089**
adv_eco* national_str				0.051*
*, **, *** indicates significant level at 1%, 5% and 10% corresponding				

Source: by authors

Patent applications (patent) demonstrate a direct, positive impact on GDP growth, with a significance at the 10% level, reinforcing the idea that innovations that lead to patents contribute significantly to economic dynamics. The interaction of patent applications with advanced economic settings (adv_eco*patent) is also significant at the 10% level. This highlights that advanced economies, with their robust infrastructural and legal frameworks, are better equipped to leverage the economic benefits of patents, potentially through enhanced commercialization opportunities and a supportive environment for innovation.

Interestingly, the number of patents per million people (patent_per1mil) also positively impacts GDP, with a significance at the 10% level. This suggests that a higher concentration of patents does not overcrowd the market but indicates a healthy, innovative environment contributing to economic growth. The positive and significant interaction with advanced economies (adv_eco*patent_per1mil), significant at the 10% level, implies that such economies have the necessary mechanisms to manage and utilize high innovation levels effectively.

The influence of a national AI strategy (national_str) on GDP growth is also positive, with the associated interaction term (adv_eco* national_str) indicating that the systematic national approach to AI in advanced economies can amplify the economic benefits. However, the interaction shows significance at the 10% level. This suggests that while national strategies are crucial, their full potential is unleashed with mature economic systems.

Beyond AI variables, traditional economic indicators such as GDP growth lag (gdp_growth_lag), gross capital formation (cap_form), and inflation (inf) show expected impacts. GDP growth lag is significantly positive across all models, indicating that past economic performance strongly predicts future growth, with significance consistently at the 1% level. Gross capital formation also positively influences GDP, which is significant at the 1% level across all models, highlighting its fundamental role in economic development. Conversely, inflation consistently negatively affects GDP growth, significant at the 1% level, suggesting that higher inflation rates may hinder economic performance, possibly due to decreased purchasing power and increased uncertainty in investment.

The box plots in **figure 5** illustrate the feature importances derived from a Random Forest algorithm with 10-fold cross-validation, focusing on different AI-related variables across several economic models. Each plot corresponds to a specific AI variable, showcasing how various features contribute to the predictive power of the models. For the model considering scholarly publications on AI (scholar_pub), the variable itself (schorlar_pub) exhibits a notably higher median importance than other features, with a broad spread of values indicated by its box plot. This suggests that scholarly publications are a key predictor in this model, highlighting the strong link between academic AI research and economic outcomes. Interestingly, the importance of advanced economy (adv_eco) is significantly lower in this model, suggesting that the effect of scholarly publications on economic output might be somewhat independent of the broader economic maturity.

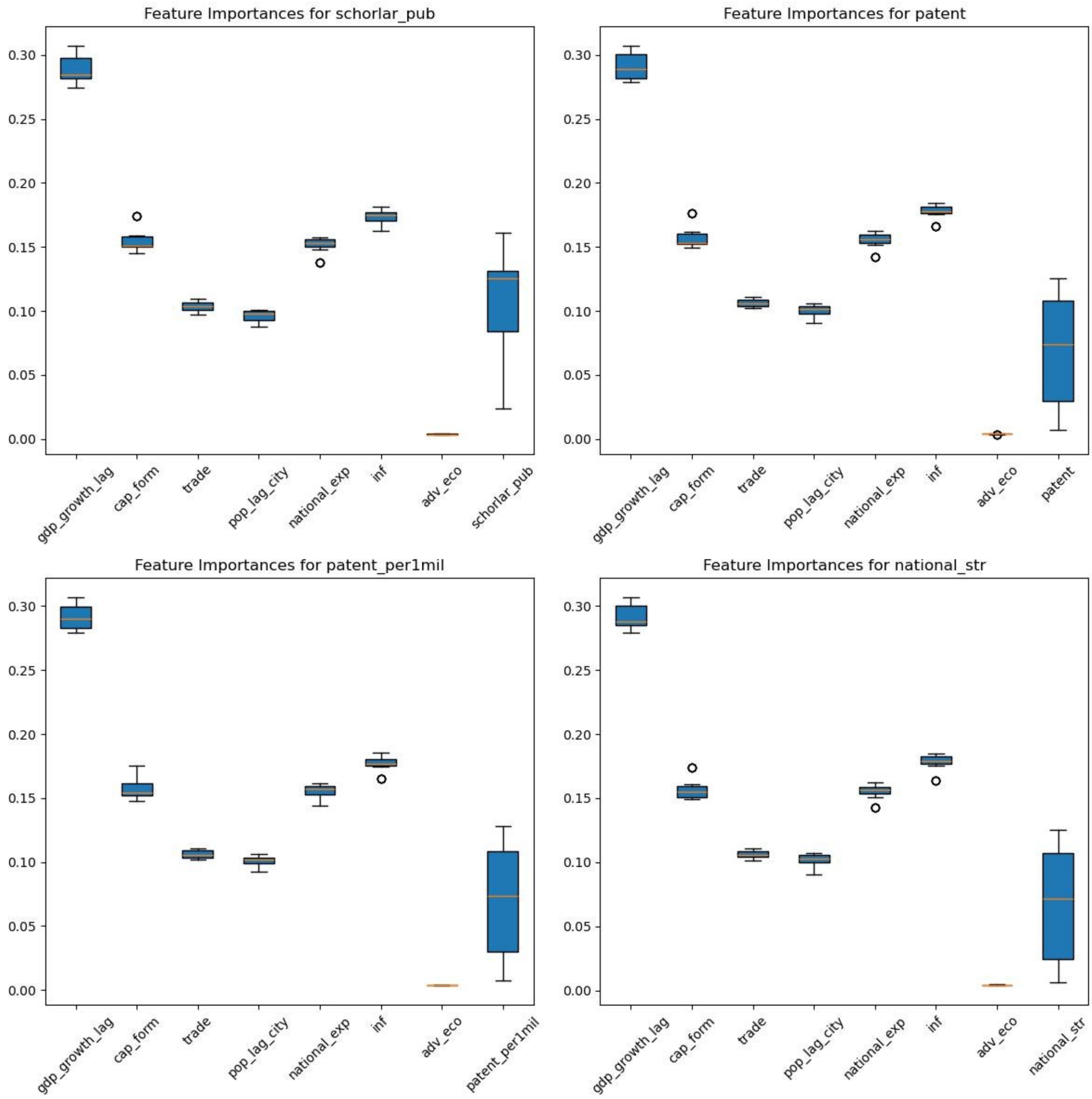

Figure 5: Feature importance of random forest algorithm with 10-fold cross-validation

Source: by authors

In the model focusing on patent applications (patent), the feature representing patent applications (patent) shows a relatively high variance in its importance, with a few outliers indicating instances where patents are particularly influential. This model reveals that, in some cases, patents can substantially impact predicting economic growth, potentially reflecting the direct economic benefits of innovative activities.

For patents per million people (patent_per1mil), the feature emerges as a prominent predictor, dominating the feature importance with a higher median value and tighter interquartile range. This underscores the significant role of dense innovation environments in economic forecasting, suggesting that higher concentrations of patenting activity are critical indicators of economic dynamism. The national AI strategy model (national_str) highlights national_str as a key feature with substantial variability in its importance. This indicates that national AI development and integration strategies are crucial for economic performance, although the spread suggests variability in how different cross-validation folds perceive its impact.

Across all models, traditional economic indicators such as GDP growth lag (gdp_growth_lag), gross capital formation (cap_form), and trade (trade) generally exhibit lower importance compared to the focal AI-related variables. This pattern aligns with the hypothesis that AI-related features might offer more direct or novel insights into economic growth dynamics within these models.

5 Conclusion & Recommendation

5.1. Conclusion

The research aimed to discern the impacts of artificial intelligence (AI) innovations on economic growth, leveraging a robust dataset from 2010 to 2023 across 141 countries. Employing advanced econometric methods, such as the System Generalized Method of Moments (SGMM), this study rigorously analyzed the effects of key AI variables like scholarly publications, patents, patents per million, and national AI strategies on GDP growth. The results confirm the significant positive impact of these AI-related innovations on economic development.

In addition to traditional econometric analysis, the study also utilized a Random Forest algorithm to determine feature importances, which provided further insights into the predictive power of different AI variables on economic outcomes. The Random Forest analysis highlighted that while all AI-related variables have a notable impact, certain features like patents per million and national AI strategies are particularly influential. These variables showed a higher median importance in the model, indicating that they are strong predictors of economic growth. Furthermore, the results of the Random Forest suggest that the integration of AI into national strategies and the density of patent filings per million people are not just contributing factors but are also key drivers of economic performance. This underscores the need for policies that foster AI innovation and patenting to enhance productivity and economic expansion.

The results of this research conclusively demonstrate that artificial intelligence innovations play a significant role in enhancing economic growth, affirming the research hypothesis established at the beginning of the study. This hypothesis was predicated on the influential theoretical frameworks of Schumpeter (2021) creative destruction and endogenous growth theories. Schumpeterian theory suggests that technological innovations disrupt existing market dynamics but also create new opportunities for growth through the process known as "creative destruction." Endogenous growth theories, proposed by scholars like Romer (1990) and Lucas Jr (1988), further emphasize that economic growth is primarily driven from within an economy through technological advances and increases in knowledge.

In this context, artificial intelligence innovations catalyze economic expansion by introducing new efficiencies and capabilities, which are fundamental for boosting productivity and economic outputs. The positive correlations between AI-related variables such as scholarly publications on artificial intelligence, patent applications, patents per million people, and national artificial intelligence strategies with GDP growth substantiate this hypothesis. These variables signify not only the generation of new technological knowledge but also the application and integration of this knowledge into the economy, which are critical processes underlined by both Schumpeterian and endogenous growth models.

Comparatively, when placed alongside previous empirical studies exploring technology's impact on economic growth, such as those by Gonzales (2023) and Furman and Seamans (2019), this research provides a more granular analysis by isolating the effects of specific AI components. For instance, Gonzales (2023) identified a broadly positive impact of AI patents on economic growth using panel data, which aligns with the findings from this study. However, our research contributes additional insights by delineating how different AI components—beyond just patents—affect economic outcomes. This confirms the general optimistic projections about AI's role in economic growth and enhances our understanding of how distinct aspects of AI contribute to these effects.

Furthermore, this study's findings also align well with the theoretical assertions from the literature review, providing empirical support that strengthens the theoretical linkages proposed by Schumpeter and modern endogenous growth theorists. The implication here is profound: as economies invest in artificial intelligence and related technologies, they foster immediate economic outputs and set the stage for sustained long-term growth by embedding these innovations into the fabric of economic activities.

In conclusion, the hypothesis that artificial intelligence innovations positively correlate with the acceleration of economic growth is based on the empirical evidence from this research. The detailed examination of individual artificial intelligence factors offers a nuanced understanding that aligns with classical and modern economic growth theories and expands the empirical landscape by providing clear evidence of how artificial intelligence contributes to economic dynamics. This serves as a robust confirmation of the initial hypothesis, reinforcing the essential role of artificial intelligence in shaping the trajectories of contemporary economic development.

5.2. Recommendation

Based on the conclusions of this research that highlight the significant positive impact of artificial intelligence innovations on economic growth, specific recommendations can be made for various stakeholders, including investors, business managers, and government agencies. These recommendations aim to leverage the study's findings to enhance economic outcomes and foster sustainable growth through the strategic deployment of artificial intelligence technologies.

Investors should consider increasing their allocations to sectors at the forefront of artificial intelligence innovation and its applications. The research indicates that areas with high artificial intelligence activity, such as tech startups focusing on artificial intelligence and established companies integrating artificial intelligence into their operations, will likely experience enhanced productivity and growth. Therefore, investors could benefit from targeting their investments towards companies that are not only developing artificial intelligence technologies but also those implementing artificial intelligence to optimize operations, enhance customer experiences, and create new products and services.

Business managers across various industries should consider adopting artificial intelligence technologies to improve efficiency and drive innovation. The research demonstrates that artificial intelligence contributes significantly to economic growth by enhancing productivity and fostering innovation. Managers should assess their current operations to identify processes that can be optimized using artificial intelligence, focusing on areas such as automation, data analytics, and customer engagement. Training programs should also be implemented to upskill employees, enabling them to effectively utilize artificial intelligence tools, thus aligning workforce capabilities with new technological advancements.

Government agencies and policymakers should focus on creating favorable environments for artificial intelligence research and development. This includes investing in educational programs that promote skills relevant to artificial intelligence, supporting R&D activities through grants and subsidies, and ensuring that regulatory frameworks are conducive to innovation while protecting public interests. The research suggests that national strategies for artificial intelligence have a significant positive impact on economic growth, particularly in advanced economies. As such, developing comprehensive artificial intelligence strategies should be a priority for governments aiming to harness the benefits of artificial intelligence for national development.

Moreover, governments should facilitate the diffusion of artificial intelligence technologies across various sectors of the economy, ensuring that small and medium enterprises (SMEs) also have access to these innovations. This could involve creating platforms for collaboration between large corporations, SMEs, and academic institutions to foster knowledge exchange and innovation. Overall, using these recommendations could help stakeholders capitalize on the economic benefits of artificial intelligence, ensuring that growth driven by technological innovation is robust, inclusive, and sustainable. By aligning investment, management practices, and policy with the insights provided by this research, all parties can contribute to and benefit from the economic potential of artificial intelligence.

5.3. Limitation & Further Research

The study presented provides significant insights into the effects of AI innovations on economic growth but carries certain limitations that warrant acknowledgment. Firstly, the data range, covering the years 2010 to 2023, offers a contemporary snapshot yet may not capture the long-term economic impacts of AI, as the integration and full effects of AI technologies can unfold over a more extended period. Secondly, the econometric models, including the System Generalized Method of Moments (SGMM), effectively address some types of endogeneity but might not account for all external variables, such as sector-specific shocks or broader economic crises, potentially limiting the generalizability of the findings.

To enhance the robustness of future research, several steps could be taken. Extending the dataset to include data before 2010 and beyond 2023 would provide a more comprehensive view of AI's long-term effects and allow for the analysis of trends over a longer timeline. Additionally, exploring more varied econometric models, such as vector autoregression (VAR) or panel cointegration, could help assess the dynamic relationships and potential long-term equilibria between AI innovations and economic outputs. Incorporating a broader array of AI impact measures, such as AI-related job creation or its effects on SME productivity, would also enrich the understanding of AI’s diverse economic impacts and offer deeper insights for policymakers and industry leaders.

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