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Determinants of AI performance and their effect on national GDP: an empirical study

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Abstract. Artificial intelligence is one of the most widely discussed topics in recent years, remarkably following the pandemic. During the pandemic, numerous industries and organizations have focused on the development of artificial intelligence due to the shift to remote learning and working. This shift also caused expanded investments and research on AI driven by the growing demand of for AI-powered tools across various sectors such as education, healthcare, and business. This paper analyses the determinants of AI performance and examines the relationship between a country's AI performance and its economic growth, measured by Gross Domestic Product (GDP). This paper employs Pearson Pairwise Correlation Multiple Linear Regression, and Simple Linear Regression models with a sample of 62 different countries to uncover the most influential factors impacting a country's AI performance and its subsequent influence on GDP. During the process of constructing the multiple linear regression model, this paper also evaluates the collinearity diagnostics such as VIF and tolerance level to prevent multicollinearity. This study finds that a country's innovation skill, featuring its research and development capabilities, is the primary driver influencing its success in AI development. Subsequently, this paper concludes that advanced AI performance can significantly contribute to a country's economic growth, further emphasizing the importance of progressive AI development.

Keywords: Artificial intelligence, multiple linear regression, Pearson correlation, economic growth.

1. Introduction

John McCarthy, known as the father of artificial intelligence, pioneered the field by proposing the idea of machines simulating human intelligence during an academic conference held at Dartmouth University in the summer of 1956 [1]. Today, AI is no longer confined to research labs but has made significant strides into various sectors, including healthcare, finance, agriculture, and transportation. Since then, artificial intelligence (AI) has progressively gained the public's attention and integrated into everyday lives in numerous forms. The imagination of self-driving cars, supercomputers, smartphones, and talking robots, which only existed in the pages of scientific fiction novels, is becoming a reality through the AI revolution [2]. From virtual assistants like Siri and Alexa to AI-driven recommendations on streaming platforms, artificial intelligence continues to reshape how individuals interact with technology in daily life. In recent years, the development of AI has been visible to the public's naked eye, and it's slowly becoming less of a dream.

AI has shown and continues to show its profound impact on society and economics worldwide in various forms [3]. Ranging from smartphones to domestic robots, AI has always been present in people's lives and provided them with personalized services. However, the development of AI has not been without controversy, particularly around privacy, bias, and the potential for job displacement [4]. As AI becomes more integrated into various sectors, concerns about the ethical use of AI, data privacy, and the possibility of increasing unemployment due to automation have surfaced, raising important questions about how AI technologies should be governed. The field of AI uses its core of machine learning skills to learn and mimic human behaviour and thinking to accomplish specific tasks assigned by humans [5]. The scope of AI ranges from weak to strong, which is determined by its functional purpose and its "degree of intelligence" relative to humans [6]. Tasks that are relatively simple, such as voice assistance and chatbots, are frequently employed in the daily appliances and are categorized as weak AI. Conversely, strong AI, which is less apparent in the daily lives, is utilized for more complex tasks. This includes the development of robots with cognitive abilities that resemble those of humans, enabling them to perform problem-solving and critical-thinking tasks. However, strong AI has not yet been fully developed and utilized in life, strong AI still requires further and thorough research before it can be safely applied in life, primarily due to ongoing and controversial ethical and moral concerns surrounding its use [7]. As a result, the study of AI has become a prominent field, attracting numerous scholars from various disciplines.

In current research articles, most scholars study the potential and future impact of integrating AI applications among various professional fields such as education, healthcare, and agriculture. These research topics are crucial for advancing AI development, as they contribute to expanding novel knowledge and educating other experts in the field. This, in turn, facilitates the integration of these insights into practical tools and applications for the public. In the research of AI in education, scholars noted that integrating AI into teaching-such as employing machine learning for image recognition and other skills-can assist teachers grade students' assignments more efficiently, thereby enhancing the overall educational experience for both teachers and students [8]. Similarly, integrating AI into technologies used in healthcare can better collect and analyse patients' information, indicating the potential for better, faster, and more cost-effective healthcare in the near future [9]. AI's potential to revolutionize healthcare by enabling predictive models and patient data analysis has been well-documented [10]. These models are capable of forecasting disease outbreaks, assisting in early diagnosis, and improving patient outcomes by tailoring treatments to individual needs. In other research on AI in the agriculture sector, authors also noted that incorporating artificial neural networks can assist farmers in predicting various aspects of the system such as water and nutrient levels [11]. AI's applications in agriculture, especially in crop management, water usage, and disease prediction, demonstrate its critical role in ensuring sustainable food production [12]. These technologies not only help optimize resource use but also mitigate risks related to climate variability and pest infestations. The use of AI technology in these existing sectors can drive the world's economy through increased productivity.

In summary, AI technology in these existing sectors can drive the world's economy through increased productivity [13]. As AI continues to evolve, it is crucial for scholars and researchers to explore a wide range of AI-related topics, including ethical considerations, regulatory frameworks, and the socio-economic impacts of AI deployment. This ongoing research is vital for advancing AI development, ensuring that its benefits are maximized while potential risks are effectively managed. This research article will analyse various factors that can influence a country's overall AI performance through the application of a multiple linear regression model. By identifying key drivers—such as investment in research and development, talent availability, and infrastructure quality—this analysis aims to provide a clearer understanding of how different elements contribute to a nation's AI capabilities. Furthermore, the study will investigate the effect of AI performance on a country's economic growth, measured by Gross Domestic Product (GDP), using a simple linear regression model. This examination will offer valuable insights into the relationship between AI advancements and economic outcomes, highlighting the potential for AI to serve as a catalyst for sustainable growth in the global economy.

2. Methodology

2.1. Data source

This paper utilized 2 different datasets for the purpose of the study. The first dataset is sourced from Tortoise website named Global AI Index. This dataset ranks the overall AI performance of 62 countries in 2022. The second dataset is sourced from World Bank, and it contains every country's 2022 Gross Domestic Product (GDP).

2.2. Data cleaning and description

The AI Index dataset includes the overall AI score for each country accompanied with factors that might affect the overall AI score of each country. These factors are organized under three primary pillars: Investment, Innovation, and Implementation (Table 1).

Table 1. Factors organized under three pillars

Investment	Innovation	Implementation
Government strategy	Research	Talent
Commercial	Development	Infrastructure
-	-	Operating environment

The overall AI score and these factors are scored from 0-100 for each country, and the impact of each of these factors on the overall AI score will be further analysed and examined. In addition, Gross Domestic Income (GDP) of these countries sourced from World Bank is also required for this study. The study will specifically target on the top 5%, middle 5%, and bottom 5% of countries based on their AI scores. The corresponding GDP of these countries will be integrated with the cleaned AI Index data after removing any extraneous information. Ultimately, the relationship between a country's overall AI performance and its GDP will be closely examined.

2.3. Methods introduction

This paper primarily utilizes Pearson Pairwise Correlation, Multiple Linear Regression Model, and Simple Linear Regression Model through RStudio and SPSS to study the relationship between variables.

2.3.1. Pearson pairwise correlation. Pearson correlation is one of the fundamental statistical methods and has been widely used to assess the strength of relationships between variables in economic studies [14]. It provides a reliable measure of the linear relationship between variables, making it an ideal tool for analysing the impact of AI performance on economic factors. The relationship can be read from the Pearson Correlation Coefficient as follows:

$$r = \frac{\sum_{i=1}^{n}(X_i-\overline{X})(Y_i-\overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i-\overline{X})^2 \sum_{i=1}^{n}(Y_i-\overline{Y})^2}} \tag{1}$$

The Pearson Correlation Coefficient r ranges from -1 to 1. A value of -1 indicates a strong negative relationship between two variables, while a value of 1 indicates a strong positive relationship between them. This paper will employ this method to assess the pairwise relationship between each factor, as well as the linear relationship of each factor with the overall AI score.

2.3.2. Multiple linear regression. Multiple Linear Regression is another fundamental tool used in the statistical field to analyse the relationship between multiple independent variables and a single dependent variable. This tool is more practical when examine the combined effect of several predictors on the outcome variable, providing a comprehensive view of how these variables interact to influence the dependent variable. The formula of Multiple Linear Regression is represented by the equation as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \epsilon \quad (2)$$

When using the multiple linear regression model, it is crucial to address potential multicollinearity within the model. Therefore, Variance Inflation Factor (VIF) will also be used to detect and evaluate any multicollinearity present in the model. If the VIF of any independent variable is greater than 5, it indicates significant multicollinearity in the model. In such cases, further actions such as removing variables may be necessary to achieve a more reliable model. This paper will employ the multiple linear regression model to assess the relationship between factors mentioned in AI index dataset (independent variables) and the overall AI score (dependent variable).

2.3.3. Simple linear regression. Simple Linear Regression is a simpler version of the multiple linear regression model where it only assesses the relationship between one independent variable and one dependent variable. This paper will utilize this model to assess the relationship between the overall AI score of all the countries and their corresponding GDP. It is also important to identify any outliers in the model and remove them, if necessary, to achieve optimal results. Cook's Distance is a useful tool to identify any substantial outliers that could potentially undermines the overall fit of linear regression model by increasing the residuals.

$$D_i = \frac{\sum_{j=1}^{n} (\hat{Y}_j - \hat{Y}_{ji})^2}{p \times MSE} \quad (3)$$

3. Results and discussion

3.1. Correlations results

Figure 1 and 2 below shows a heat map of Pearson Pairwise correlation coefficients between all the numerical variables in the AI Index dataset, along with a scatterplot matrix. Table 2 below only shows the pairwise correlation between "Total Score" (dependent variable) and factors (independent variables) accompanied with level of significance.

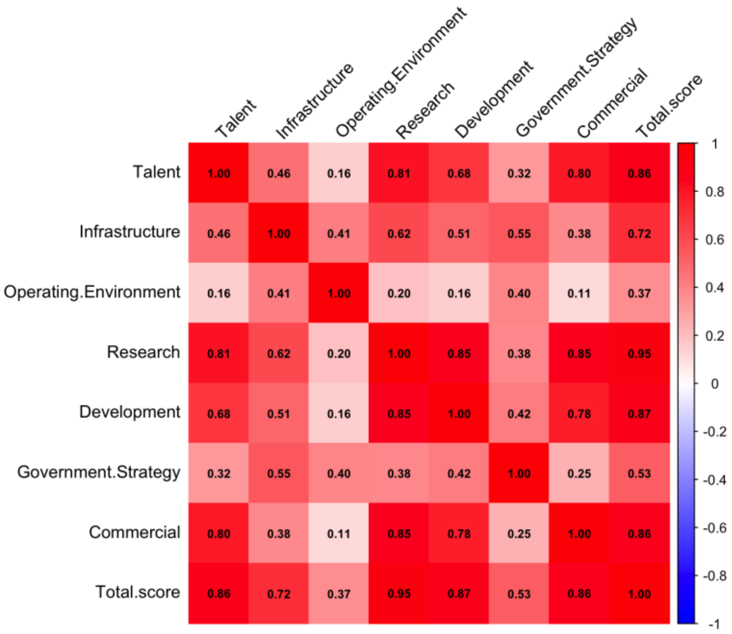

Figure 1. Heat map of Pearson Pairwise Correlation & Pairs Plot

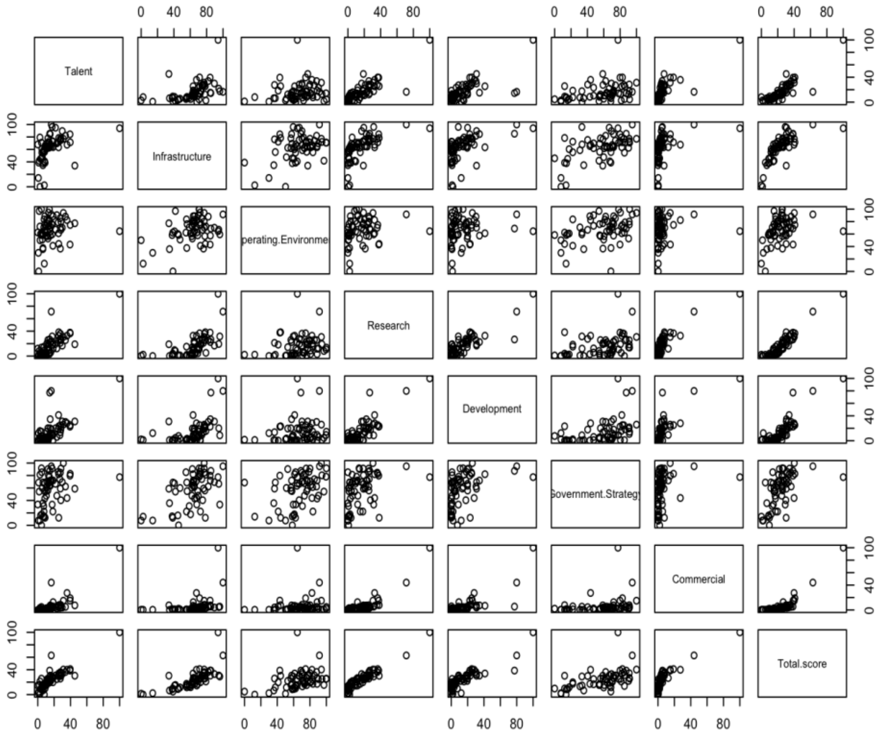

Figure 2. Pairs Plot of Pearson Pairwise Correlation

Table 2. Pairwise correlation between Total Score and Factors

	Total score
Government Strategy	0.532**
Development	0.866**
Talent	0.862**
Infrastructure	0.716**
Operating Environment	0.369**
Research	0.946**
Commercial	0.858**

* p<0.05 ** p<0.01

A strong correlation between all the factors and “Total Score” of each country can be observed through both Figure 1 and Table 2. All the factors display a statistically significant positive correlation with Pearson correlation coefficients greater than 0 and less than 1. In particularly, factor “Research” shows a substantial correlation with “Total Score” with coefficient equal to 0.946. Observing from the heat map, the factor “Research” also exhibits strong correlation with other factors such as “Talent”, “Development”, and “Commercial”. Factor “Operating Environment” shows weakest correlation with “Total Score” compared to other factors with coefficient less than 0.5 and greater than 0.

3.2. Multiple linear regression results

Observing the multiple linear regression summary, the coefficients of each factor are all statistically significant and positive with value greater than 0.

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Table 3. Multiple Linear Regression Summary (*n*=62)

	Coefficients		t	p-value	Collinearity Diagnostic	
	Beta	SD			VIF	Tolerance
Constant	-4.648	0.002	-2439.959	0.000**	-	-
Operating Environment	0.091	0.000	3550.353	0.000**	1.293	0.773
Infrastructure	0.137	0.000	3980.887	0.000**	2.363	0.423
Research	0.229	0.000	3105.174	0.000**	7.997	0.125
Development	0.137	0.000	2943.415	0.000**	3.991	0.251
Government Strategy	0.046	0.000	2063.952	0.000**	1.648	0.607
Commercial	0.229	0.000	3212.702	0.000**	4.857	0.206
Talent	0.229	0.000	4177.186	0.000**	3.376	0.296
R 2	1.000					
Adjusted R 2	1.000					
F	F (7,54) =159098533.022, p=0.000					
D-W Value	2.110					

Note:Dependent = Total score

* p<0.05 ** p<0.01

Looking at both R-squared and adjusted R-squared, the multiple linear regression model explains 100% of the variance in the dependent variable which indicates a perfect fit of the model (table 3). However, the coefficients of factor “Research”, “Commercial”, and “Talent” are interestingly all the same with value of 0.229. This violates the observations made from the Pearson Pairwise results where “Research” shows a larger correlation with “Total Score” than other factors. To understand the reasons behind this phenomenon, the author can evaluate the VIF and Tolerance of each independent variables to detect any presence of multicollinearity. The VIF of “Research” is greater than 5, but less than 10, which indicates the potential high multicollinearity of “Research” with other variables. The tolerance value of 0.125 for the variable “Research” further confirms the presence of multicollinearity among the independent variables. Reviewing the correlation heat map, the variable “Research” is strongly correlated with other variables such as “Talent”, “Commercial”, “Development” and “Total Score”. Therefore, it’s prudent to remove the variable “Result” to achieve a more accurate and optimal fit for the multiple linear regression model. This adjustment is necessary for eliminating any potential multicollinearity that may undermine the model’s performance and predictive accuracy.

Table 4 provides the multiple linear regression summary after removing the variable “Research” in the data. Observing the table, the coefficients of each variable are all statistically significant and positive with value greater than 0, this suggests that each coefficient is essential in explaining the relationship with the dependent variable, "Total Score. It’s clear that eliminating the variable “Research” is necessary and beneficial for the model. This modification has led to statistically significant alterations in the coefficients, indicating that the coefficients for "Commercial" and "Talent" are no longer identical as presented in Table 3, likely due to their strong correlation with "Research”. Eliminating the variable “Research” also enables a more accurate analysis of which factors are most and least impactful in determining the “Total Score.” The variable “Commercial” shows strongest relationship with “Total score” with a coefficient of 0.324 and “Government Strategy” shows a weakest relationship with “Total score” with a coefficient of 0.040. Looking at both R-squared and adjusted R-squared in Table 4, the multiple linear regression model (without “Research”) explains 99% of the variance in the dependent variable which indicates a perfect fit of the model. To ensure that potential multicollinearity among the variables has been fully addressed, it is necessary to evaluate the collinearity diagnostics in the new table. As the results indicate, no VIF value in any variable exceeds 5, and no tolerance level falls below 0.2, confirming that multicollinearity is no longer concerned in the new table.

Table 4. Multiple Linear Regression Summary After Eliminating Multicollinearity

	Coefficients		t	p-value	Collinearity Diagnostic	
	Beta	SD			VIF	Tolerance
Constant	-5.973	0.777	-7.685	0.000**	-	-
Talent	0.286	0.022	13.257	0.000**	2.992	0.334
Infrastructure	0.186	0.013	14.513	0.000**	1.868	0.535
Operating Environment	0.089	0.011	8.230	0.000**	1.292	0.774
Development	0.205	0.017	11.839	0.000**	3.127	0.320
Government Strategy	0.040	0.009	4.286	0.000**	1.635	0.612
Commercial	0.324	0.027	12.031	0.000**	3.959	0.253
R 2	0.991					
Adjusted R 2	0.990					
F	F (6,55) =1049.602, p=0.000					
D-W Value	1.985					

Note:Dependent Variable = Total score

* p<0.05 ** p<0.01

3.3. AI performance and economic growth

To assess the relationship between AI performance and economic growth in all countries, obtaining the values of all countries' 2022 GDP are required. Once all GDP values are collected from World Bank website, a simple linear regression model can be constructed, with "Total Score" serving as the independent variable and "GDP" as the dependent variable.

Table 5. Simple Linear Regression Summary

	Coefficients		t	p	Collinearity Diagnostic	
	Beta	SD			VIF	Tolerance
Constant	-3347.629	582.201	-5.750	0.000**	-	-
Total Score	203.076	20.623	9.847	0.000**	1.000	1.000
R 2	0.618					
Adjusted R 2	0.611					
F	F (1,60) =96.962, p=0.000					
D-W	0.502					

Note: Dependent variable = Total GDP

* p<0.05 ** p<0.01

This analysis will provide insights into how AI performance impacts the economic output of different nations (table 5 and 6). By exploring this relationship, the study aims to identify patterns and correlations that could suggest whether higher AI performance is associated with increased GDP. Additionally, it will allow for an evaluation of how different levels of AI integration into various sectors might contribute to a country's overall economic development.

Table 6. Simple Linear Regression Summary After Removing Outliers (n=59)

	Coefficients		t	p	Collinearity Diagnostic	
	B	SD			VIF	Tolerance
Constant	-217.860	286.406	-0.761	0.450	-	-
Total Score	47.433	11.684	4.060	0.000**	1.000	1.000
R 2	0.224					

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Table 6. (continued).

Adjusted R 2	0.211
F	F (1,57) =16.481, p=0.000
D-W	1.504

Note: Dependent Variable= Total GDP

* p<0.05 ** p<0.01

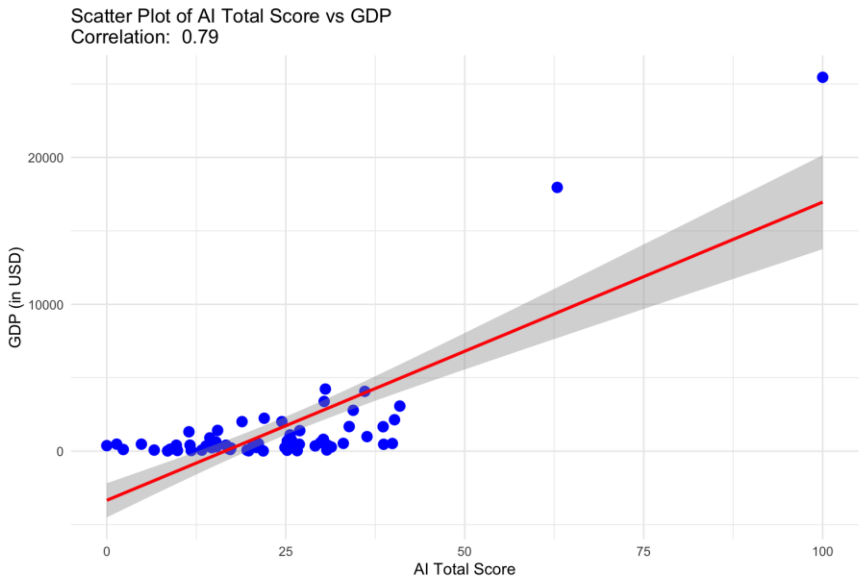

Figure 3. Scatter Plot with Fitted Regression Line

Table 6 provides a simple linear regression model that analyse the relationship between the total AI score and GDP, and Figure 3 demonstrates a scatter plot with the fitted linear regression line. From the table's output, it can be observed that the relationship between "Total score" and "Total GDP" is statistically significant and positive with a coefficient of 203.076. The R-squared value indicates that approximately 61 percent of the variance in "Total GDP" is explained by "Total Score." However, examining at the scatter plot, it's noticeable that there're outliers in the plot which could potentially compromise the accuracy of the simple linear regression model (Figure 4). Using Cook's Distance method, the outliers mathematically identified are the United States, China, and Pakistan. Both United States and China are two prominent countries with high total AI score and GDP, therefore they might have large economic scales and environment that may cause significant deviations from other countries, resulting as outliers. On the other hand, Pakistan has the lowest AI total score of 0 and GDP resulting as another outlier.

After removing the outliers (United States, China, Pakistan), it can be observed that the relationship between "Total score" and "Total GDP" is still statistically significant and positive with a new coefficient of 47.433. The R-squared value indicates that approximately 22 percent of the variance in "Total GDP" is explained by "Total Score." The regression line now fits the scatterplot more effectively, demonstrating an improved fit after the removal of these outliers.

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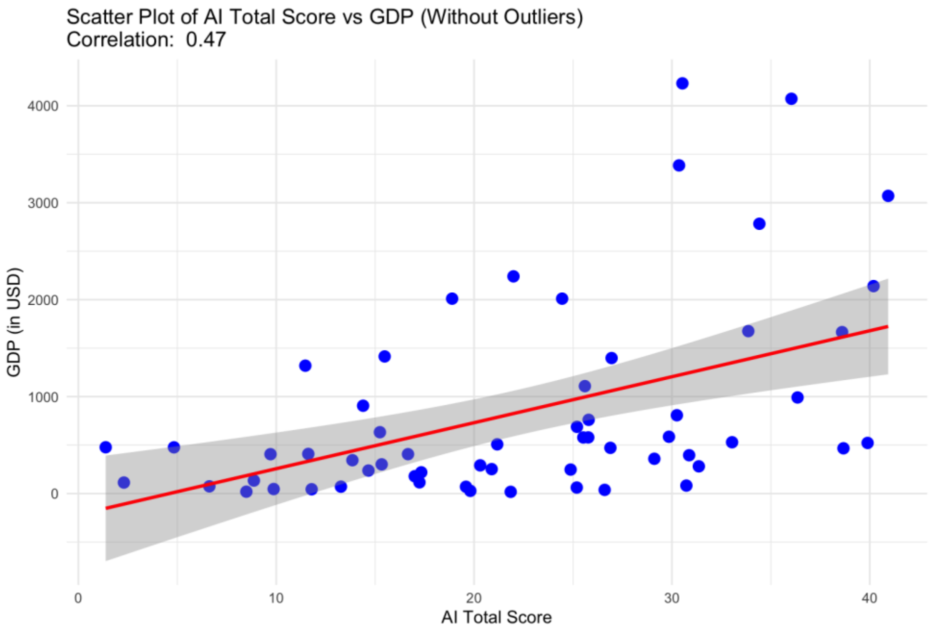

Figure 4. Scatter Plot with Fitted Regression Line (Without Outliers)

3.4. Discussion

The results of this study highlight the significant role of AI performance in influencing national economic growth. Through the application of Pearson Pairwise Correlation and Multiple Linear Regression models, it is evident that the innovation pillar, particularly research and development, has the strongest impact on a country's AI performance. This finding is consistent with other studies that emphasize the importance of research investment in driving technological advancements [15]. Countries that prioritize innovation, especially through well-developed research ecosystems, are more likely to see higher AI performance, which in turn boosts their GDP.

The multiple linear regression analysis also showed that other factors such as talent availability, infrastructure, and commercial investment have statistically significant positive effects on AI performance. While research emerged as the dominant factor, the importance of commercial strategies and talent cannot be overlooked. Commercial investment, especially from the private sector, accelerates the development and deployment of AI technologies by enabling faster innovation cycles and higher levels of productivity [16]. On the other hand, talent—reflected in the availability of skilled AI professionals-plays a crucial role in implementing and scaling AI solutions across industries. Nations with robust AI talent pools and cutting-edge infrastructure are more likely to become global leaders in AI development, as these factors directly impact their ability to innovate and implement new technologies [17]. For instance, nations like Canada and Germany have invested heavily in training programs for data scientists and AI engineers, ensuring a steady supply of talent to meet industry demands.

However, certain factors like the operating environment showed weaker correlations with AI performance. Although public perception of AI and the general business environment are important, they seem to have a relatively smaller direct effect on AI advancement compared to core elements like talent and research. This suggests that while fostering a favorable business climate is beneficial, more substantial investments in education and commercial strategies are likely to deliver greater returns in advancing AI development.

The findings from the Simple Linear Regression model further reinforce the notion that a country's AI performance is positively correlated with its GDP. The strength of this relationship suggests that effective AI technologies can become major catalysts for economic growth. This is particularly relevant

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in sectors like healthcare, agriculture, and education, where AI such as ChatGPT has already demonstrated its potential to revolutionize processes, reduce costs, and improve efficiency [18].

Nevertheless, it is important to address the limitations of this study. The presence of outliers, such as the United States and China, demonstrates that the economic scales of these nations might distort the general relationship between AI performance and GDP. Removing these outliers helped clarify the relationship for countries with more moderate AI performance, but it also raises questions about whether AI's economic impact differs at higher levels of technological advancement.

Looking forward, the study suggests that policymakers and stakeholders should prioritize building robust innovation systems and nurturing talent. As AI continues to evolve, nations that strategically invest in research, development, and commercial infrastructure are better positioned to capture the economic benefits that AI can offer. While the economic benefits are substantial, some researchers caution that the rapid advancement of AI may also lead to challenges, such as job displacement and inequality [19]. Thus, governments and industries must adopt policies that not only promote AI innovation but also mitigate potential risks [20].

4. Conclusion

This paper concludes that the development of AI is crucial to a country's economy and GDP. The positive correlation between AI performance and GDP observed in this study is supported by previous research. Several studies have shown that AI adoption acts as a key driver of productivity growth, significantly improving efficiency across various industries. Moreover, it is projected that AI technologies will contribute substantially to the increase in global GDP over the next decade, highlighting the transformative potential of AI in shaping future economic landscapes.

The development of AI can be affected through various perspectives such as a country's investment, innovation, and implementation ability. In general, a country's innovation ability is most essential for the development of AI. Innovation also consists of a country's ability for research and development. Research examines the total publications and studies in academic journals, thereby extending knowledge in the field of AI. Development focuses on creating and improving technologies used in innovative AI projects. While innovation is the primary driver of AI development, a country's capacity for investment and implementation is also crucial for developing AI technologies. Investment consists of government strategies and commercial skills. Government strategies gauge the extent of national governments' commitment to artificial intelligence by examining their spending plans and national strategies, while commercial investments focus more on businesses' dedication to AI products and technologies. Therefore, in the perspective of investment, a country's commercial ability is far more beneficial than its government's strategy for AI development. Implementation consists of a country's talent, infrastructure, and operating environment. Talent focuses on the available skilled AI experts, infrastructure assesses the quality of essential resources like electricity and the internet, and the operating environment focuses more on the public opinions toward AI. In the perspective of implementation, a country's talent is the key driver of AI development, whereas the operating environment is the least important for AI development.

In the contemporary world, AI technologies are not only capturing public attention but are also becoming deeply embedded in everyday life, transforming how we work, communicate, and make decisions. From voice-activated assistants like Siri and Alexa that streamline household tasks to AI-driven recommendation systems on platforms like Netflix and Amazon, these technologies are seamlessly integrated into personal, professional, and social spheres. As AI continues to evolve, its applications are expected to further revolutionize industries, enhance productivity, and reshape the very fabric of society. These AI technologies continue to improve lives in different sectors such as medical, business, and education. While a country's GDP is influenced by numerous factors, AI development is particularly significant due to its profound impact on people's lives. From an individual perspective, it is crucial that countries persist in their efforts to promote the development of AI, thereby enhancing the overall life quality of their citizens.

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