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The Impact of Government Expenditure and Tertiary Education on High-Technology Exports: Evidence from Asia-Pacific and European Nations

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Abstract

This study extends the growing literature on the 4th and 9th Sustainable Development Goals by examining whether tertiary education moderates the relationship between government spending on education and high-technology exports. We employ Robust Least Squares Estimation to analyze an unbalanced panel of 24 Asia-Pacific countries and 37 European nations from 2007 to 2022. This method effectively handles outliers and heteroskedasticity in panel estimations. The empirical results indicate that both a higher ratio of tertiary education enrollment and government expenditure empower high-technology exports. Our findings support human capital, innovation, and endogenous growth theories, as well as prior literature. However, the study reveals significant regional disparities in the impact of education on high-technology exports. While higher tertiary enrollment boosts high-tech exports in Asia-Pacific countries, government spending has little impact. Conversely, in European countries, government spending positively influences high-tech exports, while tertiary enrollment shows no significant effect. This study contributes practical policy implications for sustainably improving high-technology exports in Asia-Pacific and European nations by fostering human capital development and efficient government spending on education.

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1. Introduction

High-technology exports (HTE) are crucial for developing sustainable economic growth for several reasons. First, they are typically associated with high-value-added products and services, which can generate substantial revenue for exporting countries. Second, HTE can increase innovation, productivity, and competitiveness in the domestic economy. Moreover, tertiary education can significantly impact high-technology exports. Tertiary education institutions provide the advanced technical skills and knowledge necessary for innovation and technological development. Therefore, a country with a robust tertiary education system is more likely to produce highly skilled workers who can develop and deliver high-tech products and services. Additionally, government expenditure on education can also significantly impact high-technology exports. Investment in education, particularly in science, technology, engineering, and mathematics (STEM) subjects, can foster the human capital development needed for high-tech exports.

The economic development of a country is closely tied to its ability to compete in the global market for high-technology exports. Improving education quality, especially at the tertiary level, has been recognized as a crucial competitive advantage in fostering economic growth and human capital (Farayibi & Folarin, 2021; Hanushek et al., 2017; Shafuda & De, 2020). Additionally, prior studies highlight the role of government expenditure on education in promoting high-technology exports, contributing to innovation, research and development (R&D), and overall technological advancement (Mazzucato, 2013). Specifically, education quality is the focus of the 4th Sustainable Development Goal (SDG4), which aims to ensure inclusive and equitable education and promote lifelong learning opportunities for all. Promoting high-tech exports is critical because high-quality education produces a more competent workforce. Workers with strong technical skills and advanced knowledge in science, technology, engineering, and mathematics (STEM) fields are better equipped to drive innovation and technological advancements, thereby increasing high-technology exports. Unfortunately, few studies provide quantitative evidence of this relationship.

This study focuses on Asia and Europe for several reasons. Firstly, the Asia-Pacific region is one of the fastest-growing areas globally, with many countries experiencing rapid economic growth and development in recent decades. It is home to leaders in innovation and technology, such as Japan, South Korea, Taiwan, and Singapore. These countries have well-developed education systems and substantial investments in R&D, making them ideal for studying the link between education, government expenditure, and high-tech exports. Additionally, emerging economies in Asia, such as China, India, and Vietnam, have gradually increased their share of high-tech exports. These countries are becoming significant players in the global supply chain, offering competitive manufacturing capabilities and attractive investment environments.

Secondly, Asian economies are deeply integrated into global supply chains, playing crucial roles in producing, assembling, and distributing high-tech products. This integration enhances efficiency but also exposes these economies to global economic fluctuations and disruptions. Moreover, Asian countries face challenges such as rising labor costs, competition, and concerns over intellectual property protection. However, there are also opportunities for growth through continued investments in research and development, fostering innovation, and adapting to evolving market demands. The region's rapid advancement is directly relevant to SDG 9, which emphasizes the need to foster innovation and sustainable industrialization.

Similarly, European countries have a long-standing tradition of educational excellence and innovation. This is evident in their world-renowned universities and research institutions, which have produced numerous groundbreaking discoveries and influential scholars. Many European countries have invested significantly in their education systems, ensuring that citizens have access to quality education at all levels. Furthermore, European economies have historically been at the forefront of technological advancements. Countries like Germany, France, and the United Kingdom have been pioneers in engineering, manufacturing, and research and development. These nations have a rich history of industrialization and innovation, laying the groundwork for their continued success in the high-tech sector.

By examining how tertiary education and government expenditure impact high-technology exports, this study contributes to the growing literature on SDG 9. Despite the recognized importance of education and government spending, there is a lack of quantitative evidence on how these factors impact high-technology exports across different regions. Therefore, this study aims to address the following key research questions:

1. How does tertiary education enrollment affect high-technology exports in Asia-Pacific and Europe?
2. How does government expenditure impact education and high-technology exports in these regions?
3. Are there significant regional differences in the drivers of high-technology exports between Asia-Pacific and European nations?

We analyze data from 24 Asia-Pacific and 37 European countries, utilizing the World Bank database, to explore these questions. We implement Fixed Effects Models and Robust Least Squares to analyze an unbalanced panel of 61 countries in the Asia-Pacific and European regions from 2007 to 2022. Our empirical results indicate that higher tertiary education positively influences high-technology exports. Specifically, a 1% increase in tertiary enrollment boosts high-technology exports by 0.053%. Studies by Hanushek et al. (2017), Farayibi and Folarin (2021), and Shafuda and De (2020) demonstrate that tertiary education is directly associated with national competitiveness in the high-technology sector. A well-educated workforce with advanced skills is better prepared to innovate and contribute to the expansion of high-technology exports. Moreover, our findings show that a 1% increase in government expenditure on education also enhances high-technology exports by 0.523%. According to Mazzucato (2013), Aghion et al. (2016), Sandu and Ciocanel (2014), and Cirera and Maloney (2017), government investment in education is essential for promoting

innovation and advancing technology. Our findings support human capital, innovation, and endogenous growth theories.

Additionally, our research highlights regional differences in the drivers of high-tech exports. In the Asia-Pacific region, higher tertiary education enrollment significantly boosts high-tech exports, while government spending on education does not have a significant impact, possibly due to a mismatch with industry needs. Conversely, in Europe, government expenditure on education strongly enhances high-tech exports, reflecting better alignment with industry demands. Furthermore, while Europe's high-tech exports are less affected by traditional trade, the Asia-Pacific region benefits from integrating traditional trade sectors with high-tech industries, leveraging cross-border trade of intermediate goods.

Our research paper contributes to the growing literature on the 4th and 9th Sustainable Development Goals in several ways. Our study closely relates to previous studies, such as Navarro Zapata et al. (2024) and Peña-Vinces and Audretsch (2021), which examine how education, labor markets, and innovation capacity affect high-technology exports. However, these studies do not explore the impacts of government spending on developing education systems to increase high-technology exports. Moreover, while Navarro Zapata et al. (2024) used a fixed-effects panel regression model, a commonly used method for analyzing panel data, our study complements Pervez and Ali (2024) by employing Robust Least Squares, particularly the M-estimator method, to handle financial data affected by outliers and heteroskedasticity, which can undermine the reliability of standard methods such as Ordinary Least Squares (OLS) and Fixed Effects Models (FEM).

The subsequent sections of the paper are structured as follows: Section 2 introduces theories and literature reviews. Section 3 describes the data and methodology. Section 4 presents the empirical results. Section 5 discusses the findings. Finally, Section 6 concludes the study.

2. Literature Review

2.1 Background Theories

Government expenditure on education plays a significant role in influencing high-technology exports, as investments in education lead to the development of a skilled workforce, which subsequently drives innovation and growth in high-tech sectors. The endogenous growth theory (Romer, 1990) underscores the importance of government expenditure on education in fostering a skilled workforce that contributes to innovation and growth in high-technology industries. By focusing on human capital development, innovation, and technological progress as drivers of long-term economic growth, Romer (1990) posits that government investments in education are essential for creating a skilled workforce capable of boosting productivity in high-tech sectors, ultimately leading to increased high-technology exports. He argues that government expenditure on education is crucial for developing a workforce that can drive innovation and productivity in high-tech sectors, resulting in greater high-tech exports.

The Human Capital Theory (Becker, 2009) also highlights a positive relationship between investment in education, skill development, and high-tech exports. According to this theory, the most significant investments in human capital are made in education, and the advancement of scientific and technical knowledge leads to increased labor efficiency and enhanced productivity in other production inputs. Becker (2009) emphasizes that investing in education and skills development creates a more well-educated and skilled workforce, especially in high-tech sectors, which are highly valuable in industries reliant on advanced technology. By developing labor skills, high-tech companies can more easily find suitable employees, thereby boosting productivity and increasing high-technology exports. Becker also underscores the importance of government expenditure on education in enhancing both the quality and quantity of human capital, which is essential for attracting high-tech firms to invest and operate in a country.

The Innovation Theory (Fritsch, 2017) suggests that developing new products, processes, and technologies is crucial for economic growth and competitiveness. This theory posits that innovation is key to increasing high-technology exports. Tertiary education plays a vital role in innovation by producing highly skilled workers, researchers, and entrepreneurs who can develop and apply new knowledge to create innovative products and processes. Therefore, a well-developed tertiary education system is crucial for accumulating and transferring knowledge, which is a key driver of innovation. Countries with higher levels of tertiary education are expected to have higher levels of high-technology exports. Although there may not be direct evidence supporting the negative impact of tertiary education on high-technology exports in the Asia-Pacific region, it is important to consider the unique context and challenges facing each country when examining the relationship between tertiary education and high-tech exports.

The interaction between government expenditures and tertiary education can significantly impact high-tech exports in Asia-Pacific countries. Human Capital Theory (Schultz, 1971) posits that investing in education and training leads to increased productivity and economic growth, which can drive higher levels of high-tech exports. Education and training foster the development of a skilled workforce capable of producing high-quality, innovative products. These investments provide the knowledge and skills necessary to produce high-tech goods and services, a form of human capital that can spur the development of new technologies and innovations, thereby driving the growth of high-tech industries. Furthermore, investing in education helps develop a workforce capable of producing high-quality products, increasing the competitiveness of high-tech exports in the global market. As a result, a higher-quality tertiary education system can enhance human capital, improving a country's ability to produce and export high-tech goods.

2.2 The Nexus Between Tertiary Education and High-Technology Exports

Tertiary education significantly impacts high-technology exports. A well-educated workforce is essential for innovation, research, and development, all of which contribute to the growth of high-technology industries. Zhou et al. (2021) examine the role of technological capabilities in industrialization and economic development, highlighting the importance of tertiary education in building these capabilities and contributing to high-technology exports. Similarly, Mansfield (2019) and Evenson (2019) find that countries with higher-quality

tertiary education tend to have a larger share of high-technology exports in their overall trade. Pelinescu (2015) also emphasizes the importance of human capital, particularly higher education, in technological diffusion and economic growth. They argue that a highly educated workforce is essential for absorbing new technologies and developing high-technology industries. Their findings further underscore the economic benefits of policies that enhance higher education.

Moreover, government policies on education significantly influence tertiary education (Benos & Karagiannis, 2016). According to Newman (2014), national governments must ensure access to tertiary education, as it can provide underprivileged students with better career and income opportunities, thereby reducing social inequality. Countries with better-educated populations, particularly those with high-quality tertiary education, experience faster economic growth and higher high-technology exports. Therefore, based on the above arguments, we propose the following hypothesis:

Hypothesis 1: Tertiary education is positively related to the growth of high-technology exports.

2.3 The Nexus Between Government Expenditure on Education and High-Tech Exports

Previous studies report a positive relationship between government spending and high-tech exports. Mazzucato (2013) and Aghion et al. (2016) highlight the role of public investments in education in positively influencing high-tech industries and their export potential. Similarly, Sandu and Ciocanel (2014) emphasize the positive effects of education on high-tech exports, illustrating the importance of government expenditure targeted toward education. Government spending on innovation and education encourages technology transfer, enabling industries to effectively produce and export high-tech products and services (Cirera & Maloney, 2017). However, the impact of government spending on education and high-tech exports can vary depending on a nation's stage of economic development. For instance, Lee (2013) suggests that the optimal growth strategy for a developing nation may differ from that of a developed nation. In developing countries, investing in education and workforce training might be more crucial than solely focusing on research and development. These investments can help foster innovation, technology transfer, and human capital development, ultimately leading to increased high-tech exports. On the other hand, developed countries may benefit more from investing in advanced educational programs and supporting high-tech startups. By emphasizing government expenditure on education, the potential for growth and innovation in high-tech sectors can be significantly enhanced.

On the contrary, some studies report a negative relationship between government expenditure on education and high-technology exports. For instance, excessive spending on education without proper allocation and efficiency may lead to wasted resources and limited returns on investment (Hanushek et al., 2017). Farayibi and Folarin (2021) argue that misallocating funds may result in suboptimal investments in education, which may not lead to the desired improvements in human capital. Additionally, government expenditure on education does not always coincide with enhancements in educational quality and infrastructure. As a result, the benefits for high-technology sectors may not materialize (Hanushek et al., 2017; Farayibi & Folarin, 2021). In certain cases, investments in education may focus on outdated curricula and

teaching approaches, failing to equip students with the necessary skills to excel in high-tech industries. Given these mixed findings on the relationship between government spending on education and high-tech exports, we propose the following hypothesis:

Hypothesis 2: Government expenditure on education positively increases high-technology exports.

3. Data and Methodology

3.1 Data

Based on the World Bank's 2010 classification, this study compiles data from 24 countries in the Asia-Pacific and 37 countries in Europe, covering the period from 2007 to 2022. Following the approach of Duong et al. (2022), we exclude observations with insufficient data to calculate the necessary variables. The final sample is an unbalanced panel with 666 yearly observations from the Asia-Pacific and European regions between 2007 and 2022. The list of countries is provided in Appendix A.

3.2 Variable Definitions

3.2.1 Tertiary Education

Tertiary education (TER) refers to post-secondary education, with each country having its own system, though there are common trends across Asia. One notable trend is the rapid growth of higher education. In recent years, many countries in the region have invested significantly in their tertiary education systems, increasing the number of universities, colleges, and other institutions. Generally, tertiary education in Asia is diverse and dynamic, providing students with ample opportunities to pursue their educational goals. Zapata et al. (2023) provide compelling evidence of a positive and statistically significant relationship between human capital, represented by tertiary education, and total high-tech exports, contributing to economic growth. As the region continues to develop, tertiary education is expected to play an increasingly important role in both its economy and society. Following Oreopoulos et al. (2013), we estimate the enrollment ratio as the percentage of gross enrollment in tertiary education.

3.2.2 Government Expenditure on Education

Government funding for education, also referred to as educational expenditure or fiscal commitments to education, involves the allocation of financial resources by governments to support a wide range of educational programs, projects, and initiatives. These funds target primary, secondary, and tertiary education, as well as vocational training and research and development within the education sector. Financing for education is primarily derived from taxation, borrowing, or money creation, and it plays a crucial role in shaping a nation’s educational landscape and fiscal policy (Gemmell et al., 2013). Government expenditure on education is a key determinant of the quality and accessibility of education within a country or region. It aims to guarantee access to quality education for all citizens, foster economic development, and reduce social disparities. Government expenditure on education can be measured as a percentage of a nation’s gross domestic product (GDP) or as a percentage of total government spending.

3.2.3 High-Technology Exports

High-technology exports are products with high R&D intensity, such as aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery. These exports refer to the trade of sophisticated and knowledge-intensive products, including computers, semiconductors, medical devices, and aerospace equipment. The High-Technology Exports (HTE) index measures the total value of exports with high technological content, including electronics, computers, aerospace, telecommunications, and biotechnology. The OECD has developed a four-way classification of exports—high, medium-high, medium-low, and low-technology—based on the relative importance of research and development expenditures compared to the gross output and value added by different industries producing export goods (United Nations, 2024).

3.3 Model Construction

Bournakis and Tsoukis (2016) demonstrate that tertiary education positively impacts high-technology exports. However, Marginson (2016) argues that tertiary education may reduce high-technology exports. To test the impact of tertiary education on high-tech exports and examine Hypothesis 1 in the context of innovation theory, we propose Model 1 as follows:

$$\text{HTE} = a_0 + a_1 \text{TER}_{it} + a_2 \sum X_{it} + \alpha_i + \alpha_t + \varepsilon_{it} \quad (1)$$

In this study, we examine the impact of Government Expenditure on Education (EXP) on High-Tech Exports (HTE), as suggested by Crespi et al. (2019), who find a positive relationship between EXP and HTE. However, Afonso (2015) reports an adverse effect of EXP on HTE growth. To explore this further, we construct the second model to investigate the causal relationship between government spending on education and high-tech exports. This model is used to test endogenous growth theory and Hypothesis 2, as follows:

$$\text{HTE} = a_0 + a_1 \text{EXP}_{it} + a_2 \sum X_{it} + \alpha_i + \alpha_t + \varepsilon_{it} \quad (2)$$

Following Crespi et al. (2019) and Bournakis and Tsoukis (2016), we explore the interactive impacts on high-technology exports by setting up a model where high-technology exports depend on EXP, TER, and other control variables. This model aims to test human capital theory and Hypothesis 3. The primary regression to research relationship among the variables is as follows:

$$\text{HTE} = a_0 + a_1 \text{TER}_{it} + a_2 \text{EXP}_{it} + a_4 \sum X_{it} + \alpha_i + \alpha_t + \varepsilon_{it} \quad (3)$$

where HTE is a percentage of manufactured exports, EXP_{it} is the percentage of total government expenditure. TER_{it} is the percentage of gross enrollment in tertiary education. $\sum X_{it}$ is the vector of control variables. α_i is the country-fixed effect, and α_t is the time-fixed effect. The ε is the residual, and a_0 is the constant. All variable definitions are explicitly displayed in Appendix B.

3.4 Estimation Methodology

First, we use Pooled Ordinary Least Squares (OLS), Fixed Effects Model (FEM), and Random Effects Model (REM) to perform the panel data estimations. To determine the most appropriate estimation method, we then apply the Hausman and Redundant Fixed Effect Tests. However, standard estimation methods such as OLS, FEM, and REM can suffer from asymptotic inefficiency and heterogeneity, which can significantly impact the results (Duong et al., 2022; Le et al., 2023). To address these issues, we apply Robust Least Squares Estimation to mitigate potential heteroskedasticity, endogeneity, and unobserved heterogeneity.

The robust least squares method is particularly advantageous for economic analysis with panel data due to its ability to mitigate the impact of outliers, heteroscedasticity, and non-normality—common issues in economic datasets. Traditional methods like OLS are sensitive to these problems, which can distort results. In contrast, robust methods such as Huber's M-estimator assign lower weights to outliers, providing more accurate and reliable estimates (Huber, 1964). Additionally, these methods are better suited for handling the complex structures often found in panel data, including varying periods and cross-sectional dependence, thus enhancing the robustness and efficiency of the analysis.

4. Empirical Results

4.1 Descriptive Statistics

Table 1 presents the descriptive statistics of the main variables. The mean value of high-technology exports is 16.296%, indicating that high-tech goods comprise a modest portion of exports in Asia-Pacific and European countries. However, the large standard deviation and range suggest that while some countries prioritize high-tech industries, others are still in the process of developing this sector. The average gross enrollment ratio in tertiary education is 63.525%, with a standard deviation of 24.321%, indicating moderate variability across countries. Finally, governments in these regions allocate, on average, about 12.370% of their total expenditure to tertiary education, reflecting a substantial commitment to education. The variability in spending, with a standard deviation of 3.005%, suggests that while some countries prioritize education funding, others allocate a smaller proportion of their budgets to education.

Table 1: Descriptive statistics

Variables	N	Mean	Median	Std. Dev.	Maximum	Minimum
HTE	666	16.296	12.495	12.544	70.544	0.000
TER	666	63.525	67.642	24.321	150.202	24.475
EXP	666	12.370	11.978	3.005	22.435	2.196
GDP	666	2.274	2.508	4.350	24.475	-28.759
INF	666	3.621	2.136	6.057	75.277	-9.654
MET	666	85.420	68.795	55.685	419.962	21.434

Note: Table 1 reports the descriptive statistics. The final sample includes 24 countries in the Asia Pacific region and 37 countries in Europe from 2007 to 2022. All variables are described in Appendix B.

4.2 Pearson Correlation Matrix

Table 2 presents the Pearson correlation matrix. All correlation coefficients are less than 0.3, indicating weak correlations between the independent variables. We also conducted the Variance Inflation Factor (VIF) test to check for multicollinearity. All VIF values are below 2, confirming that there is no multicollinearity in our sample (Duong et al., 2022).

Table 2: Pearson correlation matrix

Variables	TER	EXP	GDP	INF	MET	VIF
TER	1					1.099
EXP	-0.114***	1				1.116
	(0.003)					
GDP	-0.257***	0.173***	1			1.100
	(<0.001)	(<0.001)				
INF	-0.059	0.075*	0.086**	1		1.014
	(0.126)	(0.052)	(0.027)			
MET	0.107***	0.249***	0.024	-0.021	1	1.089
	(0.006)	(<0.001)	(0.544)	(0.594)		

Note: Table 2 reports the Pearson correlation matrix for independent variables. The final sample includes 24 countries in the Asia Pacific region and 37 countries in Europe from 2007 to 2022. All variables are described in Appendix B. P-values are in parentheses. The symbols ***, **, and * presented significance at the 1%, 5%, and 10% levels, respectively.

4.3 Regression Results

The results from the Hausman and Redundant Fixed Effect tests indicate that the Fixed Effects Model (FEM) is more suitable than the Random Effects Model (REM) and Ordinary Least Squares (OLS). Table 3 shows that most variables, such as EXP, GDP, and INF, do not significantly impact the dependent variable. However, the coefficient for TER is positive in relation to HTE, suggesting that higher tertiary education enrollment is associated with an increase in high-tech exports. Specifically, a 1% increase in TER leads to a 0.056% increase in HTE. On the other hand, MET consistently demonstrates a significant negative relationship with HTE, indicating that countries with a higher proportion of merchandise trade tend to have lower high-tech exports. A 1% increase in MET results in a 0.172% decrease in HTE, holding all other variables constant. This finding suggests that countries focused heavily on merchandise trade might be more engaged in trading traditional goods than high-tech products.

However, the Wald test reveals that the FEM estimation results violate the heterogeneity assumption. The Durbin-Watson statistics indicate that there is no autocorrelation issue. Le et al. (2023) and Nguyen et al. (2024) argue that FEM can suffer from inefficiency and heterogeneity, as it may overlook potential endogeneity. Pervez and Ali (2024) highlight that Robust Least Squares, particularly the M-estimator method, is more efficient

in handling financial data affected by outliers and heteroscedasticity, which can undermine the reliability of standard methods like OLS and FEM. Therefore, we re-estimate the findings using the Robust Least Squares method, and the results are reported in Table 4

Table 3: Regression results using the Fixed Effects Models

Variables	Model 1	Model 2	Model 3
TER	0.058*		0.056*
	(0.056)		(0.067)
EXP		-0.176	-0.147
		(0.327)	(0.411)
GDP	-0.041	-0.024	-0.033
	(0.432)	(0.655)	(0.541)
INF	-0.012	-0.012	-0.013
	(0.791)	(0.781)	(0.774)
MET	-0.037*	-0.041**	-0.038*
	(0.079)	(0.049)	(0.067)
C	15.887***	22.098***	17.981***
	(<0.001)	(<0.001)	(<0.001)
R-squared	0.849	0.849	0.849
Adjusted R-squared	0.833	0.832	0.833
F - Statistic	52.884	52.606	52.053
Prob (F – Statistic)	<0.001	<0.001	<0.001
Country Fixed	Yes	Yes	Yes
Period Fixed Effect	Yes	Yes	Yes
N	666	666	666
Hausman (Prob)	<0.001	<0.001	<0.001
Redundant Fixed Effect (Prob)	<0.001	<0.001	<0.001
Wald Test (Prob)	<0.001	<0.001	<0.001
Durbin Watson Statistic	0.521	0.520	0.521

Note: Table 3 represents the estimation results from FEM. The sample has 24 countries in the Asia Pacific region and 37 countries in Europe from 2007 to 2022. All variables are described in Appendix B. P-values are in parentheses. The symbols ***, **, and * presented significance at the 1%, 5%, and 10% levels, respectively.

Table 4 presents the Robust Least Squares estimation results. The P-value of the R-squared statistic is below 10%, strongly rejecting the null hypothesis that all coefficients (excluding the intercept) are equal to zero. This underscores the significance of the independent variables in explaining the variation in the dependent variable. Robust Least Squares effectively addresses issues related to outliers and heteroscedasticity, thereby providing reliable estimates.

Table 4: Regression results using Robust Least Squares estimation.

Variables	Model 1	Model 2	Model 3
C	10.116***	7.576***	4.651**
	(<0.001)	(<0.001)	(0.014)
TER	0.057***		0.053***
	(<0.001)		(0.001)
EXP		0.581***	0.523***
		(<0.001)	(<0.001)
GDP	0.087	-0.005	0.059
	(0.296)	(0.957)	(0.490)
INF	-0.346***	-0.423***	-0.391***
	(<0.001)	(<0.001)	(<0.001)
MET	-0.010	0.012*	0.009
	(0.108)	(0.072)	(0.171)
R-squared	0.059	0.061	0.070
Adjusted R-squared	0.053	0.056	0.063
Rw-squared	0.108	0.115	0.128
Adjusted Rw-squared	0.108	0.115	0.128
Rn-squared statistic	57.148	74.608	77.785
Prob (Rn-squared stat.)	<0.001	<0.001	<0.001
N	666	666	666

Note: Table 4 represents the estimation results from Robust Least Squares. The sample has 24 countries in the Asia Pacific region and 37 countries in Europe from 2007 to 2022. All variables are described in Appendix B. P-values are in parentheses. The symbols ***, **, and * presented significance at the 1%, 5%, and 10% levels, respectively.

4.4. Robustness results

Robustness results are shown in Table 5 which are discussed in the following section.

Table 5: Robustness results using Robust Least Squares estimation in different regions.

Variables	Asia Pacific Nations	European Nations
C	-3.632	12.070***
	(0.382)	(<0.001)
TER	0.127***	-0.025
	(<0.001)	(0.206)
EXP	0.353	0.486***
	(0.186)	(0.001)
GDP	0.180	0.080
	(0.503)	(0.328)
INF	-0.485**	-0.318***
	(0.025)	(<0.001)

Variables	Asia Pacific Nations	European Nations
MET	0.187***	-0.014
	(<0.001)	(0.131)
R-squared	0.340	0.072
Adjusted R-squared	0.320	0.062
Rw-squared	0.737	0.101
Adjusted Rw-squared	0.737	0.101
Rn-squared statistic	518.959	44.097
Prob (Rn-squared stat.)	<0.001	<0.001
N	168	498

Note: Table 5 represents the robustness estimation results from Robust Least Squares. The sample has 24 countries in the Asia Pacific region and 37 countries in Europe from 2007 to 2022. All variables are described in Appendix B. P-values are in parentheses. The symbols ***, **, and * presented significance at the 1%, 5%, and 10% levels, respectively.

5. Discussion

Table 4 shows that tertiary enrollment has a positive and highly significant impact on high-tech exports. A 1% increase in TER leads to a 0.053% increase in HTE. This result suggests that higher tertiary enrollment is linked to greater technology exports, underscoring the role of advanced education in driving technological advancements in Asia-Pacific and European countries. The results validate human capital theory, which posits that investments in education and training lead to higher levels of high-tech exports. Additionally, the findings support innovation theory, which indicates that a well-developed tertiary education system is crucial for accumulating and transferring knowledge, a key driver of innovation and increased high-tech exports. These results align with the work of Zhou (2021), Pelinescu (2015), Mansfield (2019), Evenson (2019), Newman (2014), and Benos and Karagiannis (2016). Furthermore, the findings support human capital theory, innovation theory, and Hypothesis 1.

Table 4 also indicates a positive relationship between government expenditure on education and high-tech exports in the Asia-Pacific region and European nations. Specifically, a 1% increase in EXP is associated with a 0.523% increase in high-tech exports, emphasizing the critical role of educational investment in boosting the competitiveness of high-tech industries. These results are consistent with the findings of Mazzucato (2013), Aghion et al. (2016), Sandu and Ciocanel (2014), and Cirera and Maloney (2017), who suggest that government expenditure on education is crucial for driving innovation and technological advancement. The positive association between EXP and HTE also supports Hypothesis 2 and aligns with Human Capital Theory (Becker, 2009) and Endogenous Growth Theory, which propose that investments in education enhance labor quality, fostering innovation and growth in high-tech sectors.

However, these results contrast with those of Farayibi and Folarin (2021), who argue that excessive spending on education without proper allocation and efficiency can lead to wasted resources and limited returns on investment. Misallocation of funds may result in suboptimal investments in education, failing to

improve human capital and innovation within high-tech industries. In certain cases, investments in education may focus on outdated curricula and teaching methods that do not equip students with the necessary skills to excel in high-tech industries. While investments in education are essential for fostering innovation and developing a skilled workforce, they must be targeted effectively to maximize their impact on high-technology exports.

Furthermore, Table 4 demonstrates a negative relationship between inflation and high-technology exports in Asia-Pacific nations. Specifically, a 1% increase in inflation is associated with a 0.391% decrease in high-tech exports. This result suggests that higher inflation rates may adversely affect high-tech exports, potentially increasing uncertainty and reducing investment in high-tech industries. Our finding is consistent with Gani (2009).

However, the results in Table 4 indicate that GDP does not have a statistically significant relationship with HTE. This finding contrasts with Gani (2009), who suggests that low-income countries with lower technical achievement and growth levels may need to focus on developing high-tech products to compete in the global trading environment while enhancing their growth.

Similarly, the findings show that MET has a statistically insignificant relationship with HTE in most models. However, Model 2 reveals a significant positive relationship, suggesting that traditional merchandise trade can enhance high-tech export activities in certain contexts. This result contrasts with Tebaldi's (2011) findings, which report a negative relationship, indicating that an emphasis on traditional trade could detract from high-tech industry development.

Table 5 indicates a positive and statistically significant relationship between tertiary enrollment (TER) and high-technology exports (HTE) in the Asia-Pacific region, which may reflect the region's emphasis on rapidly expanding its educational infrastructure to meet the demands of a growing high-tech sector. Our findings are consistent with recent studies by Zapata et al. (2024) and Watchekon et al. (2015), which show that increasing tertiary enrollment is directly linked to developing a skilled workforce, crucial for innovation and the growth of high-technology industries. In contrast, Table 5 also shows that the lack of a statistically significant relationship between TER and HTE in Europe may be due to several factors. Europe generally has more established and mature educational systems with high tertiary enrollment levels. Therefore, tertiary education may have a less pronounced impact on high-tech exports than in regions where education systems are still expanding. Additionally, European high-tech export success may rely more on factors such as research and development (R&D) investments and innovation ecosystems, rather than simply the number of individuals enrolled in tertiary education. According to Sozen and Tufaner (2019), R&D spending is a critical factor in fostering innovative development, which helps shift a nation's exports to high-tech goods. Moreover, Topcu (2022) demonstrated a positive correlation between R&D expenditure and HTE for 24 OECD nations between 1996 and 2015. Finally, the differing significance of tertiary enrollment in the two regions could also reflect differences in how education is integrated into broader economic and industrial policies. In the Asia-Pacific

region, there may be stronger alignment between educational expansion and the needs of the high-tech sector, whereas in Europe, the link between education and high-tech exports may be mediated by other factors, such as industry-specific policies, innovation systems, or economic diversification.

Table 5 also highlights a significant regional disparity in the relationship between government expenditure on education (EXP) and high-technology exports. In the Asia-Pacific region, the positive association between EXP and HTE is not statistically significant, which may be attributed to factors such as the misalignment between industrial demands and educational outcomes, variable education quality, and underdeveloped innovation systems. Posso (2011) suggests that despite increased government expenditure on education, particularly in Indonesia, its effectiveness in boosting high-tech exports is limited due to these systematic issues. In contrast, Europe demonstrates a robust and statistically significant positive relationship between EXP and HTE, reflecting a more effective alignment of educational systems with industry requirements and a strong emphasis on R&D. This result is consistent with the findings of Meo and Usmani (2014), who reported that European countries with increased spending on R&D, the establishment of more universities, and the growth of scientific publications contribute positively to the generation of patents and high-technology exports.

Finally, the relationship between MET and HTE presents a nuanced picture. In Europe, the lack of a significant relationship between MET and HTE suggests that traditional trade sectors do not directly impact the region's high-tech export performance, likely due to the well-established and specialized nature of high-tech industries that operate independently of traditional merchandise trade. On the other hand, in the Asia-Pacific region, the positive and significant relationship between MET and HTE indicates that countries in this region may still rely on integrating traditional trade sectors with high-tech industries, potentially using merchandise trade as a channel to boost technology-intensive exports. This reliance on integrating traditional trade sectors with high-tech industries in the Asia-Pacific region could be driven by several factors, including the region's focus on manufacturing and assembly operations that require a blend of conventional and advanced technologies. The existence of robust international production networks in East Asia, as discussed by Ando and Kimura (2005) and further highlighted by Masuyama (2004), has facilitated the cross-border movement of intermediate goods and components crucial for high-tech production. This network-driven trade model supports the idea that merchandise trade remains a vital component of high-tech export strategies in the region, enabling these economies to leverage their comparative advantages in labor-intensive manufacturing while gradually climbing the technological ladder. This contrasts with the European model, where high-tech sectors have matured to a point where they operate more independently of traditional trade dynamics, focusing instead on innovation, R&D, and specialized manufacturing processes.

6. Conclusions

This paper explores the impact of government expenditure and the quality of tertiary education on high-tech exports in Asia-Pacific and European countries. Robust Least Squares Estimation was applied to analyze an unbalanced panel of 24 Asia-Pacific countries and 37 European nations from 2007 to 2022.

The findings highlight the significant role of tertiary education and government expenditure in boosting high-tech exports. Increased levels of tertiary education contribute positively to high-tech export growth, underscoring the value of a skilled workforce in driving technological innovation. Additionally, higher government investment in education enhances high-tech exports, reinforcing the importance of public funding in supporting technological advancement. These results align with human capital and endogenous growth theories, which emphasize the connection between educational investment and economic development. Policymakers should prioritize educational reforms and increase funding to foster a more innovative and competitive high-tech sector.

Robustness tests reveal significant regional disparities in the determinants of high-technology exports. In the Asia-Pacific region, tertiary education enrollment emerges as a key driver of high-tech exports, reflecting the region's emphasis on educational expansion. However, government expenditure on education has little impact on high-tech exports in this region, possibly due to a misalignment between educational outcomes and industrial demands. In contrast, Europe demonstrates a strong positive relationship between government expenditure on education and high-tech exports, indicating a more effective alignment of educational systems with industry requirements. The relationship between traditional merchandise trade and high-tech exports also varies across regions. While Europe's high-tech exports are largely independent of traditional trade, Asia-Pacific countries benefit from integrating traditional trade sectors with high-tech industries, facilitating the cross-border movement of intermediate goods and components.

These findings suggest that policymakers in the Asia-Pacific region should prioritize aligning educational systems with the needs of the high-tech sector while also exploring strategies to enhance the effectiveness of government expenditure on education. Furthermore, fostering stronger linkages between traditional trade sectors and high-tech industries could further boost the region's high-tech export performance. This study contributes practical policy implications for improving high-technology exports and promoting sustainable economic growth in Asia. Policymakers should initiate a comprehensive evaluation of their existing policies and strategies supporting high-tech industries, ensuring that resource allocation is optimized to maximize the sector's potential. This evaluation process will enable policymakers to identify areas where government expenditure can be more effectively directed, promoting innovation and technological advancements in high-tech industries. Furthermore, governments need to establish a conducive environment by providing appropriate incentives and support mechanisms for firms engaged in technology commercialization and export. By encouraging technology transfer and international trade, policymakers can stimulate high-technology exports and enhance the region's competitiveness in the global market. Investing in

higher education institutions is crucial for equipping individuals with technical knowledge and promoting innovation and entrepreneurship. Lastly, policymakers must improve labor productivity by investing in education and training programs that produce skilled workers capable of producing high-quality goods and services that compete globally.

In brief, the policy implications derived from this research emphasize the need for policymakers to re-evaluate existing government policies and strategies, focusing on optimizing resource allocation, fostering innovation and technology transfer, investing in higher education institutions, and enhancing labor productivity. By implementing these policy recommendations, the Asia-Pacific and European regions can enhance their high-technology exports and achieve sustainable economic growth in the long term.

While this research contributes to the growing literature on global sustainable development goals, it has some limitations. Firstly, the study does not fully disclose the short-term and long-term causal relationships between government expenditure, tertiary education, and high-technology exports. Additionally, it may not account for contextual factors such as cultural or political influences that may affect the relationship between government expenditure, tertiary education, and high-technology exports. Future studies are recommended to employ panel ARDL estimation to differentiate between the short-term and long-term effects of government expenditure and tertiary education on high-technology exports.

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Appendix A: List of countries by region

NO	ASIA PACIFIC REGION	NO	ASIA PACIFIC REGION	NO	EUROPE REGION	NO	EUROPE REGION
1	Australia	20	Philippines	1	Albania	20	Lithuania
2	Bangladesh	21	Singapore	2	Andorra	21	Luxembourg
3	Bhutan	22	Sri Lanka	3	Austria	22	Malta
4	Brunei Darussalam	23	Thailand	4	Belarus	23	Moldova
5	Cambodia	24	Vietnam	5	Belgium	24	Netherlands
6	China			6	Bulgaria	25	Norway
7	Fiji			7	Croatia	26	Poland
8	Hong Kong SAR, China			8	Czechia	27	Portugal
9	India			9	Denmark	28	Romania
10	Indonesia			10	Estonia	29	Russian Federation
11	Japan			11	Finland	30	Serbia
12	Korea, Rep.			12	France	31	Slovak Republic
13	Lao PDR			13	Germany	32	Slovenia
14	Macao SAR, China			14	Greece	33	Spain
15	Malaysia			15	Hungary	34	Sweden
16	Mongolia			16	Iceland	35	Switzerland
17	Myanmar			17	Ireland	36	Ukraine
18	New Zealand			18	Italy	37	United Kingdom
19	Pakistan			19	Latvia		

Appendix B: Variables definition

Variables	Name	Definition
HTE	High-Technology Exports	Following Fu et al. (2011), we estimated the HTE as a percentage of high-technology exports over total exports.
EXP	Total Government expenditure on education	Following Farayibi and Folarin (2021) and Shafuda and De (2020), we estimate government expenditure on education as a percentage of total government expenditure.
TER	School enrollment at the tertiary level	Following Oreopoulos et al. (2013), we estimate the enrollment ratio as the percentage of gross enrollment in tertiary education.
GDP	Gross domestic product growth rate	Following Banday et al. (2021), we estimate the GDP annual percentage growth rate, calculated at a constant local currency.
INF	Inflation rate	Following Alvarado et al. (2017), inflation is estimated from the consumer prices index.
MET	Merchandise Trade	Following Felbermayr et al. (2014), we estimate Merchandise Trade as a percentage of GDP