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**Exploring the Symmetric and Asymmetric Impact of Air Transport,
Financial Development on Economic Growth in South Korea**

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Abstract

This study examines the symmetric and asymmetric effects of air transport and financial development on economic growth in South Korea. Both the linear Autoregressive Distributed Lag (ARDL) model and the nonlinear Autoregressive Distributed Lag (NARDL) model are employed using annual data spanning the period 1980–2023. The cointegration results obtained from both the ARDL bounds test and the NARDL bounds test confirm the existence of a long-run equilibrium relationship among the study variables. The ARDL estimations designate that air transport and financial development exert a negative and statistically significant effect on economic growth in both the short and long run. In contrast, the NARDL results reveal significant asymmetric effects. Specifically, positive shocks to air transport have a positive and statistically significant impact on economic growth in both the short and long run. Moreover, both positive and negative shocks to financial development significantly influence economic growth, with positive shocks promoting economic growth and negative shocks constraining it. These findings highlight the importance of accounting for nonlinear and asymmetric relationships when examining the roles of air transport and financial development in promoting economic growth.

Keywords: air transport, financial development, economic growth, ARDL, NARDL, South Korea.

Jel: C10; C30; E43; L83

Introduction

The air transport sector is a vital and effective component of the modern transport system, given its pivotal role in supporting economic development and promoting trade and investment between countries. In recent decades, this sector has witnessed remarkable global expansion, driven by increasing globalization and the growing interconnectedness and integration of national economies. This has contributed to increased demand for air transport services and solidified its position as a strategic sector supporting economic growth and international connectivity. As a result, many countries have invested heavily in modernizing airport infrastructure, expanding airline networks, and improving tourism services to enhance their international competitiveness.

Currently, the aviation sector has become an essential pillar of the tourism industry, facilitating international travel and strengthening trade, investment, and cultural exchange. Developments in tourism infrastructure have stimulated the growth of aviation, while increased competition among tourist destinations has encouraged countries to offer competitive airfares and high-quality aviation services supported by advanced technologies. Therefore, aviation has emerged as a key driver of sustainable economic development by improving connectivity, expanding market access, and promoting international trade associated with tourism (Thrane, 2015; Njoya, 2020).

Beyond its direct contribution to transportation, the aviation industry creates substantial economic and social benefits. It enhances the balance of payments by increasing foreign exchange earnings through tourism and international business activities, creates employment opportunities, and promotes technological innovation. Furthermore, exposure to international competition encourages more efficient allocation of economic resources, while improved connectivity facilitates knowledge transfer, business expansion, and regional integration. From a social perspective, the aviation sector strengthens interactions among people and cultures while promoting compliance with international standards and regulations that improve service quality and operational safety (Han et al., 2020).

The economic contribution of aviation extends through direct, indirect, and induced effects. Direct effects include employment and value creation generated by airlines, airports, aircraft maintenance organizations, air traffic management, aviation regulatory bodies, and passenger services such as check-in, baggage handling, catering, and onboard retail. These effects also encompass the activities of aerospace manufacturers that produce aircraft and aviation equipment (Vasigh & Pearce, 2024). Indirect effects arise from the aviation supply chain, including fuel suppliers, construction companies, aircraft component manufacturers, information technology providers, financial services, and other business support industries. Induced effects result from the spending of employees working directly or indirectly in aviation, thereby stimulating demand across retail, manufacturing, banking, hospitality, and other service industries (Button, 2022).

The global economic significance of aviation continues to increase. According to the Air Transport Action Group (ATAG, 2025), the aviation sector supported approximately 86.5

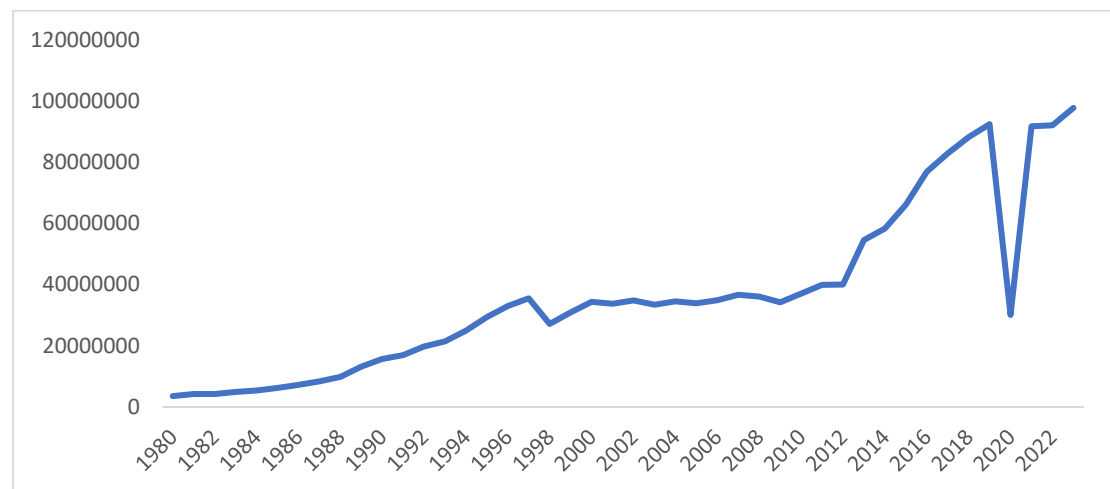
million jobs worldwide in 2023. During the same year, airlines transported around 4.4 billion passengers, including 1.8 billion international travelers and 2.6 billion domestic passengers. The industry's total contribution to the global economy reached approximately USD 4.1 trillion in 2023 and is projected to expand to USD 8.5 trillion by 2043, highlighting aviation's growing importance as a catalyst for long-term economic growth.

South Korea represents one of Asia's leading aviation markets and provides an important case for examining the relationship between aviation and economic performance. According to the World Travel & Tourism Council (WTTC, 2025), approximately 108,200 people are employed directly in South Korea's aviation industry, generating USD 19.1 billion in economic output, equivalent to 1.1% of national GDP. When indirect, induced, and tourism-related effects are considered, aviation contributes approximately USD 78.1 billion to GDP and supports around 1.2 million jobs. Aviation-related tourism alone contributes an estimated USD 21.2 billion to GDP while supporting approximately 437,700 jobs. In addition, international visitors to South Korea spend nearly USD 18.6 billion annually on goods and services, further demonstrating the aviation sector's substantial contribution to national economic activity.

South Korea has experienced remarkable growth in air transport over the past four decades. The number of air passengers increased from approximately 3.5 million in 1980 to 92.5 million in 2019, reflecting rapid expansion in aviation demand and infrastructure development. Although passenger traffic declined sharply during the COVID-19 pandemic due to international travel restrictions, the sector recovered steadily following the easing of restrictions and has returned to its long-term growth trajectory. Figure 1 illustrates the evolution of air passenger transport in South Korea over the period 1980–2023.

Despite the growing importance of aviation for economic development, empirical evidence regarding its impact remains inconclusive. While several studies report that improvements in air transport stimulate economic growth by enhancing connectivity, tourism, trade, and investment, others find weaker or nonlinear relationships depending on countries' institutional and financial conditions. Furthermore, previous studies have largely relied on symmetric econometric models, which assume that increases and decreases in aviation activity have identical effects on economic growth. Such an assumption may overlook important asymmetric responses arising from economic shocks, financial crises, or disruptions such as the COVID-19 pandemic.

Against this background, the present study examines both the symmetric and asymmetric effects of air transport and financial development on economic growth in South Korea using the Autoregressive Distributed Lag (ARDL) and Nonlinear Autoregressive Distributed Lag (NARDL) approaches. By incorporating energy consumption, social globalization, and urbanization as control variables, the study provides a comprehensive assessment of the long-run and short-run dynamics among these variables. The findings contribute to the growing literature on aviation economics by demonstrating whether positive and negative changes in air transport and financial development affect economic growth differently, thereby offering valuable policy implications for sustainable economic development in South Korea.



Source: World Bank.

FIGURE 1

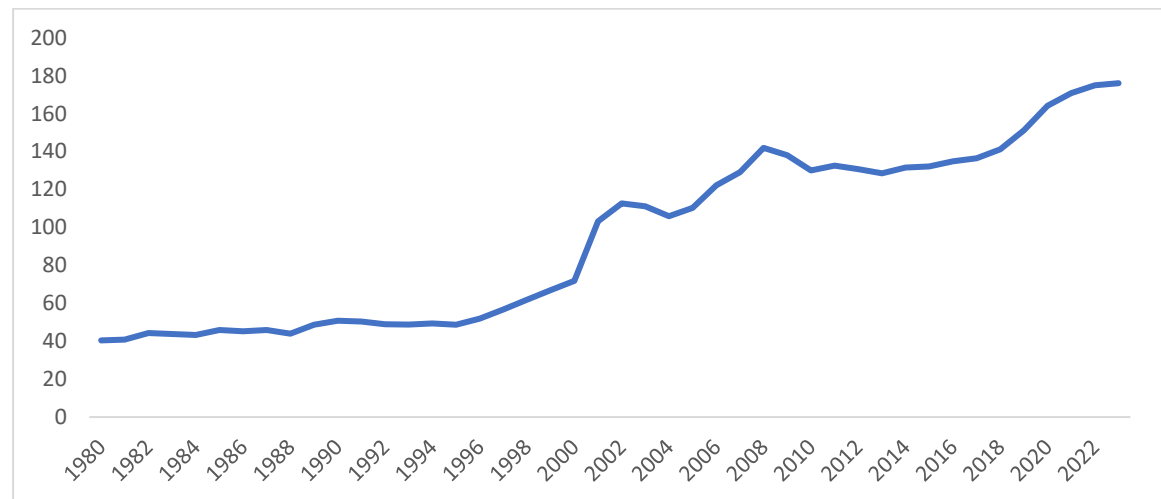
AIR TRANSPORT TREND IN SOUTH KOREA FROM 1980-2023

Financial development is widely recognized as one of the fundamental drivers of economic activity and long-term economic growth. Financial institutions perform essential functions in modern economies by mobilizing savings, allocating financial resources, facilitating investment, and providing credit to industrial, commercial, and service sectors. Therefore, the efficiency and depth of the financial system represent important determinants of economic performance. In advanced economies, financial sector development has contributed to the emergence of innovative financial instruments, improved risk management mechanisms, and enhanced access to financing, thereby supporting productivity and economic expansion.

The importance of financial development is reflected in the high level of domestic credit provided to the private sector worldwide. In 2023, domestic credit to the private sector averaged approximately 142% of GDP globally, highlighting the significant role of financial intermediaries in supporting economic activities. South Korea represents one of the notable examples of rapid financial deepening. The ratio of domestic credit to the private sector increased from 40.4% of GDP in 1980 to approximately 176% in 2023. This level exceeds that of several advanced economies, including Italy (63.5%), Germany (77.9%), France (112.7%), and the United Kingdom (119.4%).

The substantial expansion of private sector credit in South Korea reflects the close relationship between financial sector development and economic transformation, particularly during the country's rapid industrialization and export-oriented growth process. However, the relationship between financial development and economic growth is not necessarily linear. While increased credit availability can stimulate investment, innovation, and productivity, excessive credit expansion may also create financial vulnerabilities, inefficient resource

allocation, and instability. Therefore, examining both positive and negative shocks to financial development is essential for understanding its actual impact on economic growth. Figure 2 illustrates the evolution of financial development in South Korea during the period 1980–2023.



Source: World Bank.

FIGURE 2

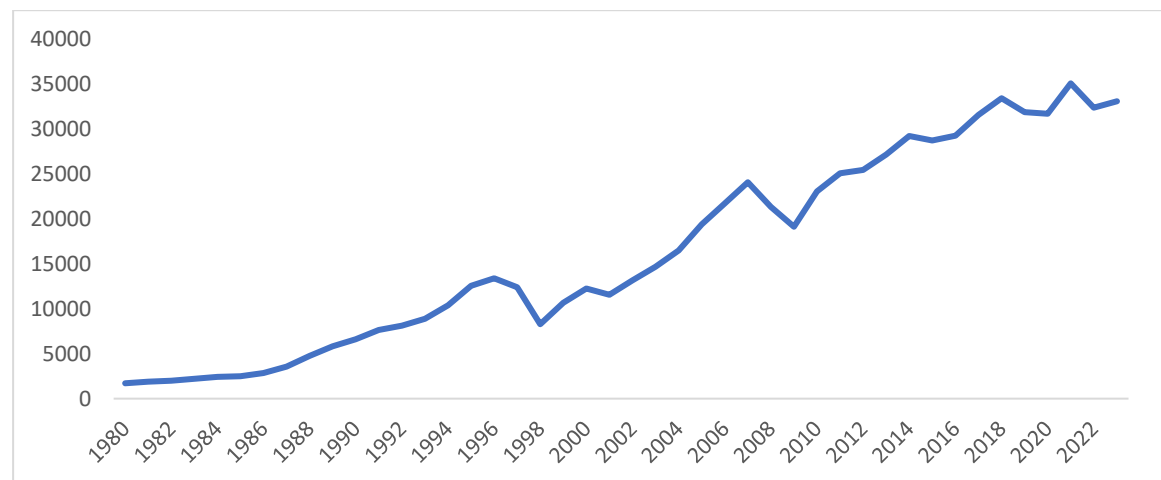
FINANCIAL DEVELOPMENT TREND IN SOUTH KOREA FROM 1980-2023

South Korea has achieved remarkable economic transformation and sustained economic growth over the past four decades. The country's development experience has been largely shaped by industrialization strategies, export-oriented growth policies, investment in human capital, and effective economic planning. These strategies played a significant role in transforming South Korea from a relatively low-income economy into an advanced industrialized economy within a relatively short period.

In 1980, South Korea's GDP per capita was approximately USD 1,715. Following the implementation of successive industrial development plans and export promotion strategies, income levels increased substantially despite facing various domestic and external challenges, including global economic fluctuations and financial crises. Through a combination of sound macroeconomic management, institutional development, technological advancement, and effective public governance, South Korea achieved remarkable improvements in economic performance. By 2023, GDP per capita had reached approximately USD 33,121, reflecting the country's successful structural transformation and integration into the global economy.

This sustained economic progress has been accompanied by significant development across various sectors, including manufacturing, technology, financial services, trade, and transportation. The South Korean experience demonstrates the importance of coordinated economic policies and productive investment in supporting long-term economic growth.

Figure 3 illustrates the evolution of GDP per capita in South Korea during the period 1980–2023.



Source: World Bank.

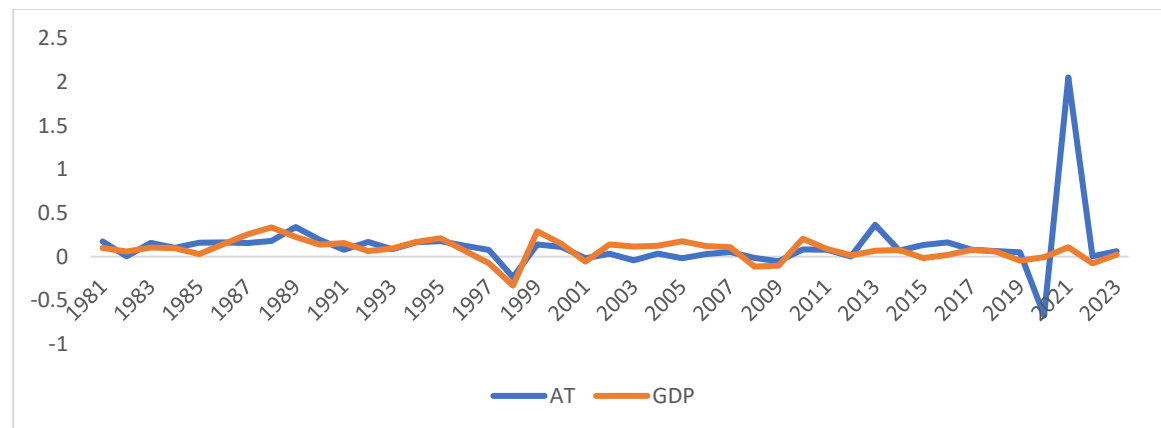
FIGURE 3

GDP PER CAPITA TREND IN SOUTH KOREA FROM 1980-2023

South Korea's economic performance during the period 1981–2023 was characterized by sustained growth despite experiencing several internal and external shocks. One of the most significant challenges was the Asian financial crisis of 1997–1998, which adversely affected many economies in the region. Nevertheless, the South Korean economy demonstrated considerable resilience and maintained its long-term growth trajectory through structural reforms, technological advancement, and effective economic management.

This economic expansion was reflected across various sectors, including the air transport industry, which experienced substantial development over the past decades. The aviation sector benefited from increasing international integration, rising income levels, trade expansion, and growing tourism activities. Although the COVID-19 pandemic caused an unprecedented disruption to global air transport by reducing passenger demand and restricting international mobility, the sector recovered significantly after the removal of travel restrictions. This rapid recovery highlights the resilience and adaptability of South Korea's aviation industry.

Figure 4 presents the growth trends of air transport and GDP per capita in South Korea during the period 1981–2023, illustrating the dynamic relationship between aviation development and overall economic performance.



Source: World Bank.

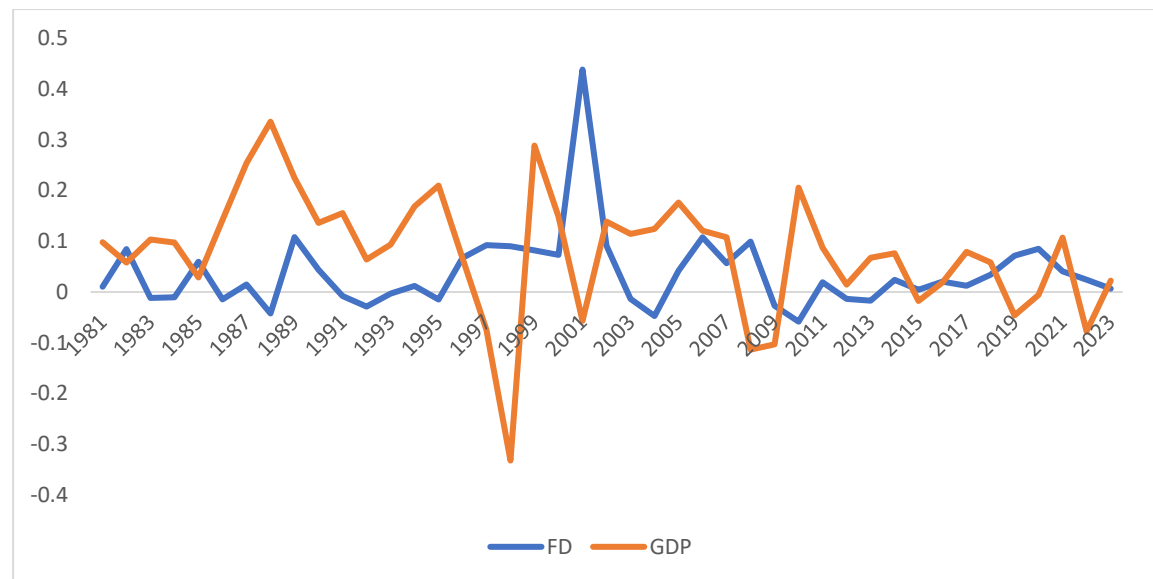
FIGURE 4

GDP PER CAPITA AND AIR TRANSPORT GROWTH RATE IN SOUTH KOREA FROM 1981-2023

Finally, it is important to highlight the apparent divergence between economic growth and financial development dynamics in South Korea during the period 1981–2023. Although financial development generally expanded alongside economic transformation, several episodes indicate that changes in domestic credit to the private sector did not always move in the same direction as economic growth. For instance, in 1988, economic growth experienced a substantial increase, while domestic credit to the private sector recorded a notable decline. Similarly, in 1998, GDP growth declined significantly following the Asian financial crisis, whereas the growth rate of domestic credit remained relatively stable. In 2001, economic growth decreased, while domestic credit to the private sector increased by approximately 44%.

These observations suggest that the relationship between financial development and economic growth in South Korea may not be linear or symmetric. In particular, expansions and contractions in credit availability may generate different economic responses depending on prevailing economic conditions, financial stability, and the efficiency of credit allocation. Therefore, the existence of positive and negative financial development shocks provides motivation for applying the NARDL approach, which allows the asymmetric effects of financial development on economic growth to be examined.

Figure 5 illustrates the evolution of GDP per capita growth and financial development growth in South Korea during the period 1981–2023.



Source: World Bank.

FIGURE 5

GDP PER CAPITA AND FINANCIAL DEVELOPMENT GROWTH RATE IN SOUTH KOREA FROM
1981-2023

Literature Review

The relationship between air transport, financial development, and economic growth has received increasing attention in the economics and transportation literature. The rapid expansion of the aviation industry over recent decades, driven by globalization, trade liberalization, and the liberalization of air transport markets, has strengthened the role of aviation as a catalyst for tourism, trade, foreign investment, and regional integration. At the same time, advances in financial systems and digital technologies have facilitated air travel by improving payment systems, expanding access to financial services, and reducing transaction costs. Consequently, both air transport and financial development have become important determinants of economic performance.

Several studies have examined the contribution of air transport to economic growth using nonlinear econometric approaches. Khanal et al. (2022) investigated the Air-Transportation-Led Growth Hypothesis (ALGH) in Australia using annual data from 1971–2019 and the nonlinear autoregressive distributed lag (NARDL) model. Their findings confirmed significant asymmetric effects in both the short and long run, demonstrating that positive shocks in air transport stimulate economic growth, whereas negative shocks exert a considerably larger adverse effect.

Similarly, Balsalobre-Lorente et al. (2020) examined the Spanish economy using the NARDL framework and reported that air transport, social globalization, and urbanization significantly promote economic growth. Their results indicated that positive changes in air transport

generate substantial long-run improvements in GDP, highlighting the importance of aviation as an engine of economic expansion.

Evidence from tourism-related studies also supports the existence of nonlinear relationships. Garrod et al. (2023), using annual data for a small island economy over the period 1976–2019, found that tourism positively contributes to economic growth; however, the relationship is asymmetric, with negative tourism shocks exerting considerably stronger effects than positive shocks. These findings suggest that transportation and tourism sectors respond differently to positive and negative economic disturbances.

The relationship between financial development and economic growth has also generated extensive empirical debate. Liu and Hsu (2006) analyzed Taiwan, South Korea, and Japan using the Generalized Method of Moments (GMM) and Principal Component Analysis (PCA). Their results revealed that financial development positively affected Taiwan's economic growth but negatively influenced South Korea and Japan. Moreover, capital outflows following financial liberalization adversely affected all three economies.

Using nonlinear techniques, Al-Khatib et al. (2023) investigated the relationship between financial development and economic growth in Algeria during 1980–2020. Applying Transfer Entropy, NARDL, and the Cumulative Dynamic Multiplier approach, the study concluded that financial development affects economic growth asymmetrically in both the short and long run, with positive and negative financial shocks producing significantly different responses.

Other studies report mixed evidence regarding the finance-growth nexus. Liang and Jian-Zhou (2006) found no significant relationship between financial development and GDP in China, while Yucel (2009) reported that financial development negatively affected economic growth in Türkiye, although trade openness promoted growth. Likewise, Kaushal and Pathak (2015) concluded that financial development did not significantly influence India's economic growth despite evidence of short-run interactions among GDP, trade openness, and financial variables.

Conversely, several studies document positive effects of financial development on economic performance. Rahman et al. (2015) identified a stable long-run relationship among financial development, international trade, and economic growth in Australia. Adamopoulos (2013) found evidence of long-run causality between financial development and economic growth in Ireland, while Akinci et al. (2014) reported long-run cointegration between financial development and economic growth across OECD countries.

Nevertheless, not all studies support a positive finance-growth relationship. Leitão (2012), using a dynamic panel System-GMM estimator for EU-27 countries, concluded that excessive domestic credit may reduce economic growth by weakening banking sector stability. These findings suggest that the impact of financial development depends on institutional quality, financial efficiency, and the productive allocation of financial resources.

Overall, previous empirical evidence remains inconclusive. While many studies report positive effects of aviation and financial development on economic growth, others identify insignificant or even negative relationships. More importantly, most previous research has examined air transport and financial development separately or has relied on conventional symmetric models that assume identical responses to positive and negative shocks.

To the best of the authors' knowledge, limited empirical evidence simultaneously investigates the asymmetric effects of air transport and financial development on economic growth in South Korea using the NARDL framework. This study addresses this gap by examining both symmetric and asymmetric relationships while controlling for energy consumption, social globalization, and urbanization. Consequently, the study contributes to the literature by providing new evidence on whether positive and negative changes in aviation activity and financial development exert different impacts on economic growth.

Model Specification and Methodology

Model Specification

Economic growth is influenced by numerous macroeconomic and structural factors, particularly in highly open economies that are increasingly integrated into global markets. South Korea represents an ideal case study because its economy relies heavily on international trade, advanced financial markets, and one of the world's most developed aviation networks. Given the strong interdependence between aviation, tourism, financial services, and international commerce, fluctuations in air transport activity and financial development are expected to influence economic performance through multiple transmission channels.

The aviation sector is highly sensitive to economic cycles, geopolitical events, financial crises, pandemics, and other external shocks. Likewise, financial development plays a crucial role in mobilizing savings, allocating capital efficiently, facilitating investment, and supporting productive economic activities. However, positive and negative changes in financial conditions do not necessarily affect economic growth symmetrically. Consequently, estimating only linear relationships may conceal important nonlinear dynamics.

To capture both symmetric and asymmetric effects, this study employs the linear Autoregressive Distributed Lag (ARDL) model developed by Pesaran et al. (2001) together with the Nonlinear Autoregressive Distributed Lag (NARDL) model proposed by Shin et al. (2014). The ARDL model estimates the average long-run and short-run relationships among the variables, whereas the NARDL framework decomposes changes in air transport and financial development into positive and negative partial sums, thereby allowing separate estimation of expansionary and contractionary effects.

Following the approaches adopted by Balsalobre-Lorente et al. (2020), Khanal et al. (2022), Raihan et al. (2024), and Shin et al. (2014), the empirical model is specified to examine the effects of air transport and financial development on economic growth while controlling for

energy consumption, social globalization, and urbanization. This specification enables a comprehensive assessment of both the long-run equilibrium relationship and the short-run adjustment dynamics among the variables.

$$GDP = f(AT, FD, X) \quad (1)$$

Where, GDP: GDP Per Capita proxy of Economic growth; AT: air Passenger carried; FD: financial development (Domestic credit to private sector % GDP); X : control variables include EU: energy consumption per capita; SG: Social globalization index; UR: Urban % of population.

By taking natural logarithm form equation

$$LGDP_t = \beta_0 + \beta_1 LAT_t + \beta_2 LEU_t + \beta_3 LFD_t + \beta_4 LSG_t + \beta_5 LU_t + \varepsilon_t \quad (2)$$

In this study, empirical specification is an econometric representation of the linear and non-linear relationship between AT, FD, EU, SG, UR and GDP per capita in the context of short-run and long-run dynamics.

B. Methodology

In this context, ARDL bounds test approach was used to estimate the symmetric the long-run and short-run relationship between the AT, FD, EU, SG, UR and GDP per capita. Based on Equation (3), the ARDL model estimates the effect of independent variables on the GDP per capita growth rate within the framework of short-run and long-run dynamics as follows:

$$\begin{aligned} \Delta LGDP_t = & \beta_0 + \beta_1 GDP_{t-1} + \beta_2 LAT_{t-1} + \beta_3 LEU_{t-1} + \beta_4 LFD_{t-1} + \beta_5 LSG_{t-1} + \beta_6 LU_{t-1} + \\ & \sum_{i=1}^q \gamma_1 \Delta GDP_{t-i} + \sum_{i=1}^q \gamma_2 \Delta LAT_{t-i} + \sum_{i=1}^q \gamma_3 \Delta LEU_{t-i} + \sum_{i=1}^q \gamma_4 \Delta LFD_{t-i} + \\ & \sum_{i=1}^q \gamma_5 \Delta LSG_{t-i} + \sum_{i=1}^q \gamma_6 \Delta LUR_{t-i} + \theta ECM_{t-1} + \varepsilon_t \end{aligned} \quad (3)$$

Where q representing the lag length of the series, Δ as the first difference operator, and θ as the coefficient of the ECM. $\beta_1 - \beta_6$ represent the long run coefficients, $\gamma_1 - \gamma_6$ represent the short run coefficients.

To investigate the positive and negative shock in air transport, financial development and its impacts on economic growth, the nonlinear autoregressive distributed lag (NARDL) methodology is considered as a brilliant econometric estimation technique for discovering the asymmetric impacts. Several reasons support employing the NARDL method, specifically its usefulness in capturing the intricate dynamics that define these economic connections. The

main validation for utilizing the NARDL method lies in its ability to discover asymmetric relationships that traditional linear models may struggle to adequately illustrate, as these conventional models assume uniform responses to changes in independent variables. In contrast, the NARDL method simplifies separate estimation of both positive and negative shocks, allowing for a more nuanced understanding of how economic variables respond to both increases and decreases in growth interventions. Furthermore, a notable advantage of employing the NARDL framework is its ability to model short-term dynamics alongside long-term associations within a single framework. This feature allows for a comprehensive examination of both immediate and enduring effects, providing a holistic view of the temporal dynamics of economic growth. Furthermore, the NARDL approach excels at addressing the nonlinearities found in economic relationships. Given the observed nonlinear effects, a modeling technique capable of accommodating the complexities in the interactions among air transport passengers, financial development, and economic growth is essential. The NARDL model's capacity to integrate nonlinear changes confirms a more accurate and realistic portrayal of these relationships, thereby filling a gap often neglected in linear analyses. Lastly, the NARDL method's significance is further improved by its robustness to the integration properties of variables. As noted by Shin *et al.* (2014), equation (2) can be reformulated within the NARDL framework as follows:

$$\begin{aligned} \ln GDP_t = & a_0 + a_1 \ln AT_t^+ + a_2 \ln AT_t^- + a_3 \ln FD_t^+ + a_4 \ln FD_t^- + a_5 \ln EU_t + \\ & + a_6 \ln SG_t + a_7 \ln UR_t + \varepsilon_t \end{aligned} \quad (4)$$

In order to examine the positive and negative shock impact of AT and FD on economic growth, the changes in the partial sum can be portrayed as follow:

$$AT_t^+ = \sum_{i=1}^t \Delta AT_i^+ = \sum_{i=1}^t \max(\Delta AT_i, 0) \quad \text{Positive shock} \quad (5)$$

$$AT_t^- = \sum_{i=1}^t \Delta AT_i^- = \sum_{i=1}^t \min(\Delta AT_i, 0) \quad \text{negative shock} \quad (6)$$

$$FD_t^+ = \sum_{i=1}^t \Delta FD_i^+ = \sum_{i=1}^t \max(\Delta FD_i, 0) \quad \text{positive shock} \quad (7)$$

$$FD_t^- = \sum_{i=1}^t \Delta FD_i^- = \sum_{i=1}^t \min(\Delta FD_i, 0) \quad \text{negative shock} \quad (8)$$

The NARDL model is utilized to explore how fluctuations in shocks, including both positive and negative changes in independent variables, impact time-series dependent variables (Neog and Yadava, 2020). Due to its accurate and reliable outcomes when the variables are in level I(0),

first difference $I(1)$, or a combination of $I(0)$ and $I(1)$, NARDL is a commonly applied technique. It also differentiates between the short-run and long-run impacts of independent variables on the dependent variable. According to the critical bounds established by Pesaran *et al.* (2001), a long-term relationship among the variables is identified when the calculated F-statistics exceed the upper bound's critical value at a 5% significance level. By integrating equations 5, 6, 7, and 8 adhering to the econometric methodology of Shin *et al.* (2014) and Villanthenkodath *et al.* (2021), we formulate the NARDL estimates for both long-run and short-run effects as outlined:

$$\begin{aligned} \Delta \ln GDP_t = & \beta_0 + \beta_1 \ln GDP_{t-1} + \beta_2 \ln AT^+_{t-1} + \beta_3 \ln AT^-_{t-1} + \\ & \beta_4 \ln FD^+_{t-1} + \beta_5 \ln FD^-_{t-1} + \beta_6 \ln EU_{t-1} + \beta_7 \ln SG_{t-1} + \beta_8 \ln UR_{t-1} + \\ & \sum_{i=1}^j \delta_1 \Delta \ln GDP_{t-i} + \sum_{i=0}^k (\delta_2^+ \Delta \ln AT_i^+ + \delta_3^- \Delta \ln AT_i^-) + \\ & \sum_{i=0}^m (\delta_4^+ \Delta \ln AFD_i^+ + \delta_5^- \Delta \ln AFD_i^-) + \sum_{i=0}^n \delta_6 \Delta \ln EU_{t-i} + \sum_{i=0}^l \delta_7 \Delta \ln SG_{t-i} + \\ & \sum_{i=0}^o \delta_8 \Delta \ln UR_{t-i} + \varphi ECM_{t-1} + \varepsilon_t \quad (9) \end{aligned}$$

Where, $\beta_1 - \beta_8$ long run impacts, $\alpha_1 - \alpha_7$ long run impacts as mentioned in equation 4, $\alpha_1 - \beta_2/\beta_1$; $\alpha_2 = -\beta_3/\beta_1$ displays the long run impacts of positive and negative shock in the air transportation on economic growth, $\alpha_4 - \beta_4/\beta_1$; $\alpha_5 = -\beta_5/\beta_1$ presents the long run impacts of positive and negative shock in the financial development on economic growth, j, k, m, n, l, o are lag orders, $\delta_1 - \delta_8$ short run impacts, $\sum_{i=0}^k \delta_2^+$ measure the impact of an increase in air transportation on economic growth in the short term, $\sum_{i=0}^k \delta_3^-$ measure the impact of a decrease in air transportation on economic growth in the short term. $\sum_{i=0}^m \delta_4^+$ measure the impact of an increase in financial development on economic growth in the short term, $\sum_{i=0}^m \delta_5^-$ measure the impact of a decrease in financial development on economic growth in the short term. Δ denotes difference operator; and ε_t is the white noise term.

The impact of dynamic asymmetric multiplier on the variables can be stated as follows:

$$m(AT)_h^+ = \sum_{j=0}^h \frac{\partial y_{t+j}}{\partial AT_{t-1}^+} = m(AT)_h^- = \sum_{j=0}^h \frac{\partial y_{t+j}}{\partial AT_{t-1}^-}, h = 0, 1, 2 \dots \quad (10)$$

$$m(FD)_h^+ = \sum_{j=0}^h \frac{\partial y_{t+j}}{\partial FD_{t-1}^+} = m(FD)_h^- = \sum_{j=0}^h \frac{\partial y_{t+j}}{\partial FD_{t-1}^-}, h = 0, 1, 2 \dots \quad (11)$$

Knowing that, as $h \rightarrow \infty$, $m(AT)_h^+ \rightarrow a_1$, and $m(AT)_h^- \rightarrow a_2$.

$$m(FD)_h^+ \rightarrow a_3, \text{ and } m(FD)_h^- \rightarrow a_4.$$

The dynamic multiplier approach enables the examination of how the endogenous variable responds differently to positive and negative changes in the explanatory variables. Following a shock to the system, the estimated multipliers trace the adjustment path of the dependent variable from the initial equilibrium toward the new long-run equilibrium. Consequently, the dynamic multiplier analysis provides a comprehensive illustration of both the magnitude and speed of adjustment associated with positive and negative shocks, thereby offering valuable insights into the asymmetric transmission mechanism captured by the NARDL model.

Data

This study employs annual time-series data for South Korea covering the period 1980–2023. Real GDP per capita, air transport (measured by passengers carried), financial development, energy consumption per capita, and urbanization were obtained from the World Development Indicators (WDI) database. Data on the Social Globalization Index were collected from the KOF Swiss Economic Institute, whose Globalization Index measures the economic, social, and political dimensions of globalization (KOF, 2023).

Before conducting the econometric analysis, descriptive statistics were examined to understand the characteristics and distribution of the variables. Table 1 presents the descriptive statistics for all variables included in the analysis. The results indicate relatively low standard deviations for all variables, suggesting limited dispersion around their respective means and indicating stable time-series behavior over the sample period. The Jarque–Bera normality test reveals that most variables are normally distributed, with the exception of $\ln EU$ and $\ln UR$, which deviate from normality. Nevertheless, the ARDL and NARDL approaches are robust to moderate departures from normality and therefore remain appropriate for the present analysis.

Furthermore, the correlation matrix indicates positive pairwise associations between economic growth and the explanatory variables, including air transport, financial development, energy consumption, urbanization, and the Social Globalization Index. These positive correlations provide preliminary evidence of potential long-run relationships among the variables; however, correlation alone does not imply causality. Consequently, further econometric procedures, including unit root testing, cointegration analysis, and ARDL/NARDL estimation, are employed to establish the existence and direction of both short-run and long-run relationships.

TABLE 1
DESCRIPTIVE STATISTICS

	LGDP	LAT	LFD	LSG	LEU	LUR
Mean	9.372	17.081	4.420	4.200	10.575	4.333
Median	9.494	17.336	4.650	4.259	10.816	4.384
Maximum	10.467	18.398	5.171	4.392	11.133	4.406
Minimum	7.447	15.087	3.698	3.884	9.384	4.038
Std. Dev.	0.936	0.928	0.526	0.164	0.586	0.104
Skewness	-0.708	-0.653	-0.065	-0.534	-0.892	-1.538
Kurtosis	2.293	2.570	1.282	1.909	2.344	4.098
Jarque-Bera	4.591	3.462	5.445	4.269	6.625	19.554
Probability	0.101	0.177	0.066	0.118	0.036	0.000
Correlation						
LGDP	1.000					
LAT	0.959	1.000				
LFD	0.898	0.827	1.000			
LSG	0.983	0.951	0.941	1.000		
LEU	0.984	0.961	0.885	0.983	1.000	
LUR	0.937	0.930	0.766	0.911	0.961	1.000

Empirical results

Before conducting the cointegration analysis, it is necessary to examine the stationarity properties of the variables through unit root tests. This preliminary step is essential because the validity of the ARDL and NARDL approaches depends on ensuring that none of the

variables are integrated of order two, $I(2)$. Furthermore, identifying the order of integration helps determine the appropriate econometric methodology for investigating the long-run relationships among the variables.

In this study, three-unit root tests were employed: the Augmented Dickey–Fuller (ADF) test, the Dickey–Fuller Generalized Least Squares (DF–GLS) test, and the Phillips–Perron (PP) test. As reported in Table 2, the results indicate that all variables are stationary either at their levels, $I(0)$, or after taking the first difference, $I(1)$. Since none of the variables exhibit integration of order two, the results confirm that the dataset satisfies the necessary conditions for applying the ARDL and NARDL cointegration approaches.

TABLE 2
THE RESULTS OF UNIT ROOT TESTS

	ADF		DF-GLS		PP	
	At level	First difference	At level	First difference	At level	First difference
L(GDP)	-2.417	-5.241***	0.397	-4.125***	-2.541	-5.241***
L(AT)	-1.721	-9.937***	-1.024	-10.218***	-1.899	-10.083***
L(FD)	-0.585	-4.801***	-1.011	-4.087***	-0.388	-4.740***
L(EU)	-4.148***	-3.804***	-0.910	-5.705***	-3.488**	-3.998***
L(UR)	-3.716***	-1.934	-1.158	-1.978**	-9.943***	-2.059
L(SG)	-2.399	-6.770***	0.866	-5.786***	-2.698*	-6.768***

*, ** and ***, 1%, 5% and 10%

Table 3 reports the results of the cointegration tests used to examine the existence of a long-run relationship among the study variables. According to the ARDL bounds testing approach, cointegration exists when the calculated F-statistic exceeds the upper critical bound value, leading to the rejection of the null hypothesis of no long-run relationship. The results indicate that the F-statistics obtained from both the ARDL and NARDL models are higher than the corresponding critical values, confirming the existence of cointegration among air transport, financial development, energy consumption, urbanization, the Social Globalization Index, and economic growth.

These findings suggest that the variables move together in the long run and that temporary deviations from equilibrium are corrected over time. Therefore, the ARDL and NARDL estimation frameworks are appropriate for analyzing both the symmetric and asymmetric

short-run and long-run effects of air transport and financial development on economic growth in South Korea.

TABLE 3
ARDL and NARDL BOUNDS TESTs

Null hypothesis: No degree of relationship					
ARDL bound Test result					
Test Statistic	Value	Significant level	I(0)	I(1)	Result
F	4.826	10%	2.08	3	Cointegrated
K	5	5%	2.39	3.38	
		2.5%	2.7	3.73	
		1%	3.06	4.15	
NARDL bound Test result					
Test Statistic	Value	Significant level	I(0)	I(1)	
F	4.707	10%	1.92	2.89	Cointegrated
K	7	5%	2.17	3.21	
		2.5%	2.43	3.51	
		1%	2.73	3.9	

*, ** and ***, 1%, 5% and 10%

Long Run ARDL And NARDL Results

After confirming the existence of a long-run relationship among the variables through the ARDL and NARDL bounds testing approaches, the ARDL model was employed to estimate the symmetric short-run and long-run effects among the study variables. Subsequently, the NARDL model was applied to examine whether positive and negative changes in air transport and financial development generate asymmetric effects on economic growth in both the short and long run.

Tables 4 and 5 present the estimation results of the linear ARDL and nonlinear NARDL models, respectively, for South Korea over the period 1980–2023. These models provide evidence on the magnitude, direction, and statistical significance of the symmetric and asymmetric relationships between air transport, financial development, and economic growth, while controlling for energy consumption, urbanization, and social globalization.

TABLE 4
LONG-RUN ESTIMATIONS OF THE ARDL AND NARDL MODELS

ARDL				NARDL			
Variable	Coeff.	t-Statistics	p-values	Variable	Coeff.	t-Statistics	p-values
L (AT)	-0.2107	-0.528	0.6019	LAT_POS	0.3028	2.462	0.0210**
				LAT_NEG	0.1522	1.048	0.3045
L (FD)	-0.7742	-1.2916	0.2079	LFD_POS	0.4381	2.046	0.0514*
				LFD_NEG	-2.763	-3.581	0.0014***
L (EU)	1.7532	1.0967	0.2828	LEU	0.9343	1.802	0.0837*
L (SG)	6.284	1.2534	0.2212	LSG	-4.347	-1.807	0.0827*
L (UR)	1.4616	0.3862	0.7025	LUR	2.742	1.846	0.0768*
C	-35.278	-2.2582	0.0326	C	4.396	0.548	0.5889

*, ** and ***, 1%, 5% and 10%

The ARDL estimation results indicate that, in the long run, air transport and financial development exert negative but statistically insignificant effects on economic growth. Specifically, a 1% increase in air transport is associated with a 0.21% decline in economic growth, while a 1% increase in financial development, measured by domestic credit to the private sector as a percentage of GDP, reduces economic growth by approximately 0.77%. Although these coefficients are negative, their statistical insignificance suggests that the linear relationship between air transport, financial development, and economic growth is not sufficiently strong when assuming symmetric effects. This finding highlights the possibility that positive and negative changes in these variables may generate different economic responses, which motivates the application of the nonlinear ARDL approach.

The NARDL results provide evidence of significant asymmetric effects between the explanatory variables and economic growth in South Korea. Regarding air transport, the long-run estimates indicate that positive shocks have a statistically significant and favorable effect on economic growth. A 1% increase in the positive component of air transport increases economic growth by approximately 0.30%. Interestingly, negative shocks to air transport also exhibit a positive effect, with a 1% decline in air transport associated with a 0.15% increase in

economic growth. This result suggests that reductions in air transport activity do not immediately translate into lower economic growth, possibly due to the resilience of the South Korean economy and the ability of other economic sectors to compensate for temporary declines in aviation activity.

With respect to financial development, the NARDL findings confirm the presence of asymmetric effects. Positive shocks to financial development have a significant positive impact on economic growth, where a 1% increase in financial development contributes to a 0.44% increase in economic growth. In contrast, negative shocks generate a substantially stronger adverse effect, as a 1% decrease in financial development reduces economic growth by approximately 2.70%. This asymmetric response indicates that contractions in financial development are more damaging than the benefits generated by equivalent expansions, emphasizing the critical role of financial stability and efficient credit allocation in supporting economic growth.

The control variables also provide important insights. Energy consumption has a positive and statistically significant effect on economic growth, with a 1% increase in energy consumption contributing to approximately 0.93% higher economic growth. This finding reflects the importance of energy availability in supporting industrial production and economic activities in South Korea. Similarly, urbanization demonstrates a strong positive effect, where a 1% increase in urbanization increases economic growth by approximately 2.70%, indicating that urban concentration enhances productivity, infrastructure development, and economic efficiency.

Conversely, the Social Globalization Index exhibits a negative relationship with economic growth. The results suggest that a 1% increase in social globalization reduces economic growth by approximately 4.30%. Although globalization is generally expected to enhance economic performance, this negative effect may reflect adjustment costs associated with rapid social integration, changes in consumption patterns, or possible distributional effects arising from globalization processes. Therefore, the impact of globalization may depend on institutional capacity and the ability of economies to transform globalization benefits into productive outcomes.

TABLE 5
SHORT-RUN ESTIMATIONS OF THE ARDL AND NARDL MODELS

	ARDL			NARDL		
	Coeff.	Prob.		Coeff.	t-Stat	Prob.
L(GDP(-1))	1.1746	0.0000	C	2.218	0.552	0.5855
L(GDP(-2))	-0.4378	0.0015	LGDP(-1)*	-0.505	-5.856	0.0000
L(AT)	-0.0737	0.2117	LAT_POS(-1)	0.153	2.474	0.0205**
			LAT_NEG(-1)	0.077	1.049	0.3041
L(FD)	-0.5042	0.0042***	LFD_POS(-1)	0.221	2.089	0.0470**
			LFD_NEG(-1)	-1.394	-3.086	0.0049***
L(EU)	2.019	0.0001***	LEU(-1)	0.471	1.740	0.0941*
L(SG)	1.6883	0.1017	LSG(-1)	-2.194	-1.851	0.0760*
L (UR)	18.648	0.0027***	LUR	1.384	1.835	0.0784*
DL(GDP(-1))	0.438	0.0001	D(LGDP(-1))	0.638	7.102	0.0000**
DL (AT)	-0.074	0.0432**	D(LAT_POS)	-0.018	-0.406	0.6881
			D(LAT_NEG)	-0.069	-1.546	0.1347
DL(FD)	-0.504	0.0005	D(LFD_POS)	-0.328	-2.720	0.0117**
			D(LFD_NEG)	-0.333	-0.624	0.5384
DL(EU)	2.019	0.0000	D(LEU)	1.898	10.292	0.0000***
DL(UR)	18.648		D(LEU(-1))	-1.942	-8.426	0.0000***
DL(SG)	1.688	0.0131	D(LSG)	0.661	1.062	0.2986
CointEq(-1)*	-0.2632	0.0000	CointEq(-1)*	-0.505	-7.478	0.0000***

*, ** and ***, 1%, 5% and 10%

The short-run ARDL estimation results indicate that air transport and financial development exert negative effects on economic growth in South Korea. Specifically, a 1% increase in air transport reduces economic growth by approximately 0.07%; however, this effect is statistically insignificant. In contrast, a 1% increase in financial development decreases economic growth by approximately 0.50%, and this effect is statistically significant. These findings suggest that, under the assumption of symmetric effects, expansion in financial development does not necessarily translate into immediate economic benefits, possibly due to inefficient credit allocation, excessive lending, or delays in the transmission of financial resources into productive investment activities.

However, the short-run NARDL results reveal significant asymmetric effects of air transport and financial development on economic growth. Regarding air transport, the positive and negative shocks generate different responses. A positive shock to air transport has a positive and statistically significant effect on economic growth, where a 1% increase in air transport activity increases economic growth by approximately 0.15%. Conversely, a negative shock to air transport also produces a positive effect, with a 1% decline in air transport associated with an increase in economic growth of approximately 0.08%. This result indicates that the short-run response of economic growth to changes in air transport is nonlinear, suggesting that increases and decreases in aviation activity do not have symmetric effects on the South Korean economy.

With respect to financial development, the NARDL estimates confirm the existence of asymmetric short-run effects. A positive shock to financial development has a significant positive impact on economic growth, where a 1% increase in financial development contributes to approximately 0.22% higher economic growth. In contrast, a negative shock to financial development has a substantially stronger adverse effect, as a 1% decline in financial development reduces economic growth by approximately 1.40%. This finding emphasizes that contractions in financial development impose greater economic costs than the benefits generated by equivalent expansions, highlighting the importance of maintaining financial stability and ensuring the efficient allocation of credit.

Among the control variables, energy consumption has a positive and statistically significant effect on economic growth. A 1% increase in energy consumption increases economic growth by approximately 0.47%, reflecting the importance of energy availability in supporting industrial production and economic activities. Likewise, urbanization contributes positively to economic growth, with a 1% increase in urbanization associated with a 1.38% increase in economic growth. In contrast, the Social Globalization Index has a negative short-run effect, where a 1% increase in social globalization reduces economic growth by approximately 2.19%. This result may indicate that rapid social globalization can generate short-run adjustment costs or structural pressures that temporarily reduce economic efficiency.

The asymmetry test provides a formal assessment of whether the estimated coefficients associated with positive and negative shocks are statistically different from each other. In other words, it examines whether increases and decreases in air transport and financial

development have identical effects on economic growth in both the short and long run. Rejecting the null hypothesis of symmetry confirms the presence of nonlinear relationships, indicating that economic growth responds differently to positive and negative changes in the explanatory variables. The results of the asymmetry tests are presented in Table 6.

TABLE 6**ASYMMETRY TESTS**

	WLR		WSR	
	F-statistic	Prob.	F-statistic	Prob.
AT	1.841039	0.1870	29.15465	0.000
FD	2.998138	0.0957	15.93370	0.000

Table 6 presents the results of the Wald test for examining the existence of asymmetric effects in the long and short run. The probability values of the Wald test for the long-run positive and negative shocks of air transport and financial development are 0.187 and 0.095, respectively. Since these values exceed the 5% significance level, the null hypothesis of symmetry cannot be rejected. This indicates that, in the long run, positive and negative changes in air transport and financial development have statistically similar effects on economic growth in South Korea. Therefore, the long-run relationship between these variables can be considered symmetric.

In contrast, the short-run Wald test results indicate that the probability values are below the 5% significance level. Consequently, the null hypothesis of symmetry is rejected, and the alternative hypothesis of asymmetry is accepted. This finding confirms the existence of nonlinear short-run relationships, implying that positive and negative shocks to air transport and financial development do not have identical effects on economic growth. Therefore, economic growth responds differently to expansions and contractions in aviation activity and financial development in the short term.

To evaluate the reliability and stability of the estimated ARDL and NARDL models, several diagnostic tests were conducted. The results, reported in the fourth section of Table 7, confirm that the estimated models satisfy the required econometric assumptions. Specifically, the residuals do not suffer from serial correlation, non-normal distribution, heteroscedasticity, or model misspecification problems. These findings provide evidence that the estimated ARDL and NARDL specifications are statistically valid and suitable for interpreting the short-run and long-run relationships among the variables.

TABLE 7

DIAGNOSTIC TESTS

ARDL			
		F-statistic	p-values
Jarque–Bera Normality Test		0.987	0.610
Breusch-Godfrey Serial Correlation LM Test		0.377	0.690
Heteroskedasticity Test: Breusch-Pagan-Godfrey		1.029	0.459
Ramsey Reset Test		0.330	0.571
R^2	0.997	Adj. R^2	0.995
F-statistic	638.38 (***)	DW	2.026
NARDL			
		F-statistic	p-values
Jarque–Bera Normality Test		0.995	0.608
Breusch-Godfrey Serial Correlation LM Test		0.659	0.527
Heteroskedasticity Test: Breusch-Pagan-Godfrey		0.626	0.833
Ramsey Reset Test		0.400	0.533
R^2	0.997	Adj. R^2	0.996
F-statistic	643.48 (***)	DW	1.831

The CUSUM and CUSUMQ tests were employed to assess the stability of the coefficients in the ARDL and NARDL model. The results of the CUSUM and CUSUMQ tests are visually represented in Figure 6 and 7.

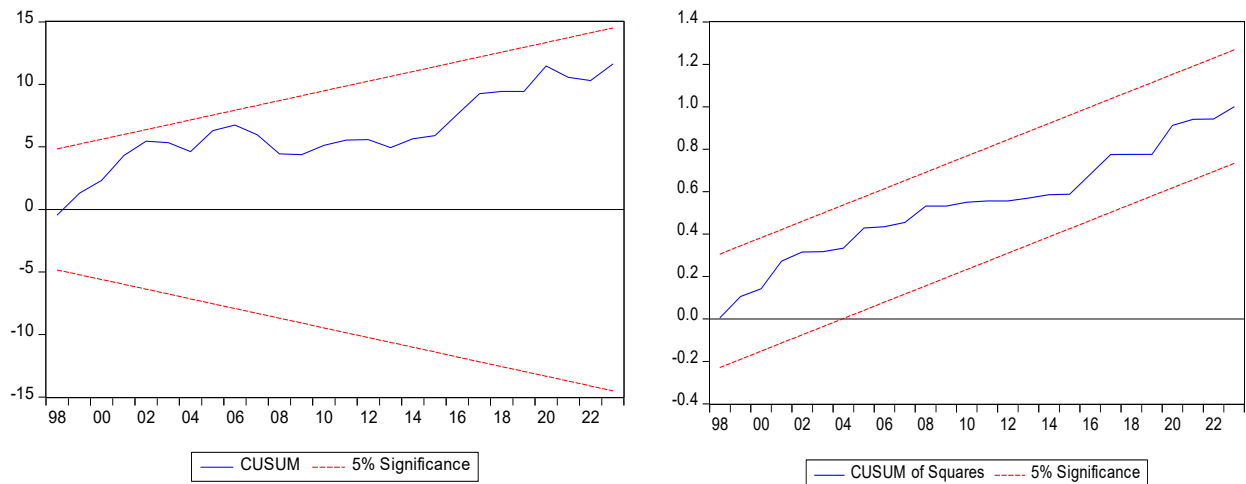


FIGURE 6

ARDL CUSUM and CUSUMQ TESTS

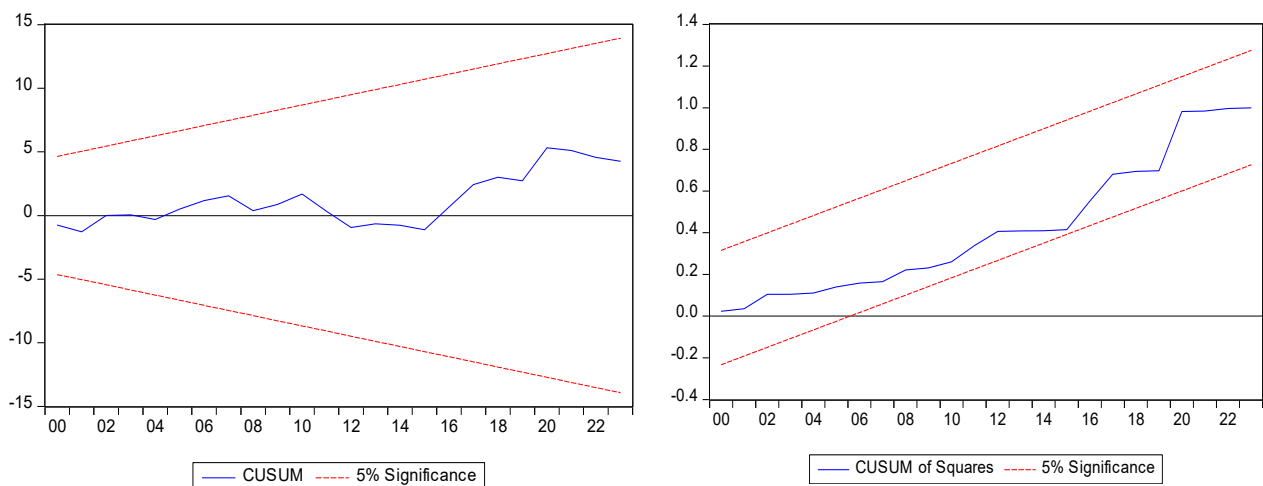


FIGURE 7

NARDL CUSUM and CUSUMQ TESTS

Figure 8 shows the asymmetric NARDL dynamic multiplier effects, which highlights the impact of both positive and negative air transport shocks on economic development. The solid black line in Figure 8 shows the positive impact of AT on GDP, whereas the dotted black line shows the negative effect of air transport on economic growth. This NARDL multiplier effects figure demonstrates the large asymmetries between the positive and negative shocks to AT and

GDP. The graph in Figure 8 illustrates the existence of a positive relationship between air transport and economic growth. The effect of a positive shock in air transport is found to dominate that of a negative shock.

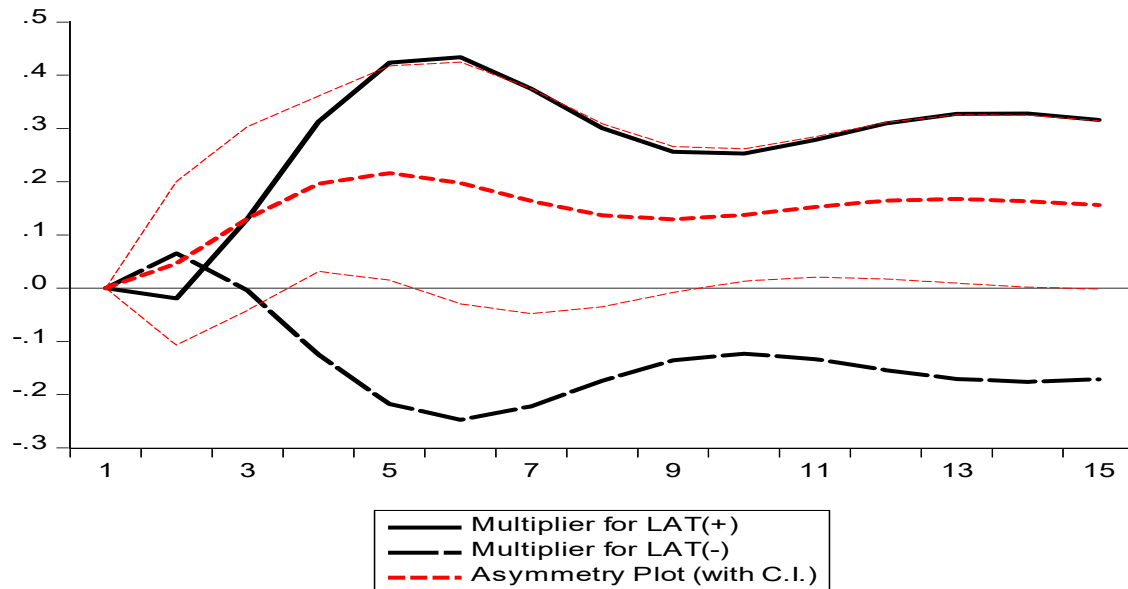


FIGURE 8

NONLINEAR AUTOREGRESSIVE DISTRIBUTED LAG MULTIPLIER GRAPH

Figure 9 shows the asymmetric NARDL dynamic multiplier effects, which demonstrates the impact of both positive and negative financial development shocks on economic development. The solid black line in Figure 9 shows the positive impact of financial development on GDP, whereas the dotted black line shows the negative effect of financial development on economic growth. This NARDL multiplier effects figure demonstrates the large asymmetries between the positive and negative shocks to AT and GDP. The graph in Figure 9 shows the existence of a negative relation between financial development and economic growth. The effect of financial development negative shock is found to dominate that of a positive shock.

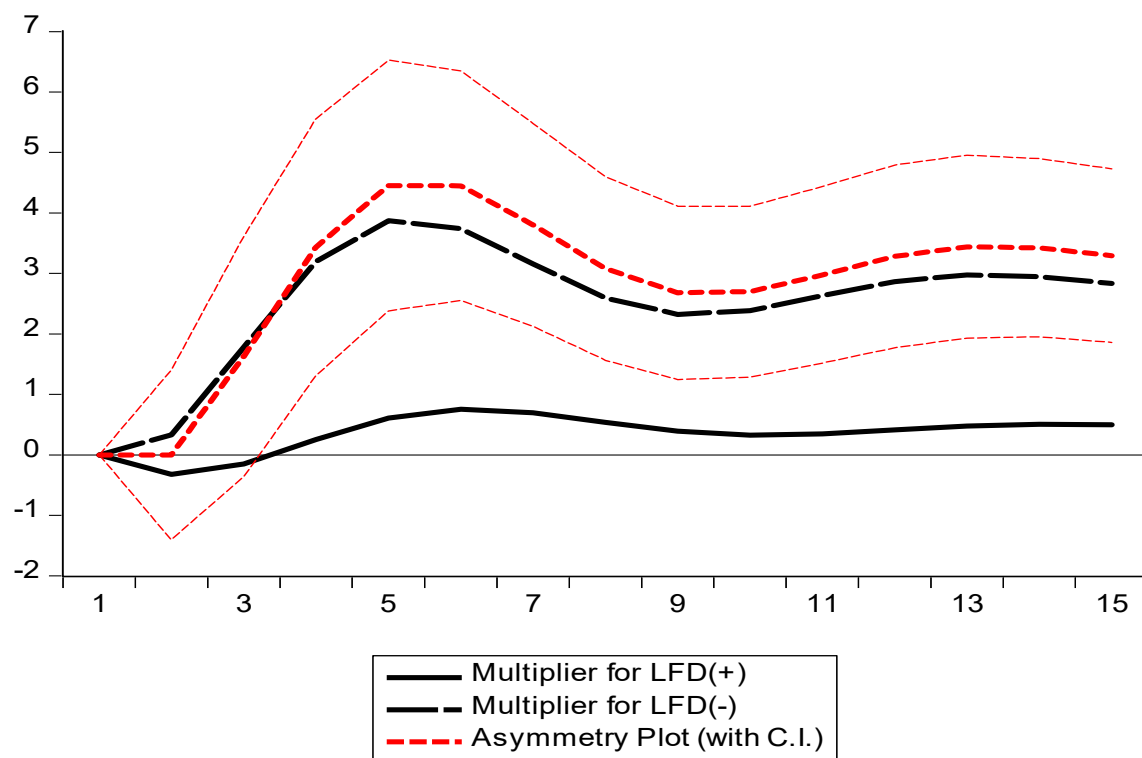


FIGURE 9

NONLINEAR AUTOREGRESSIVE DISTRIBUTED LAG MULTIPLIER GRAPH

Conclusion

This study examines the symmetric and asymmetric effects of air transport and financial development on economic growth in South Korea using the Autoregressive Distributed Lag (ARDL) and Nonlinear Autoregressive Distributed Lag (NARDL) approaches. Annual data covering the period 1980–2023 are employed. The cointegration results obtained from both the ARDL bounds test and NARDL framework confirm the existence of a long-run equilibrium relationship among air transport, financial development, energy consumption, social globalization, urbanization, and economic growth.

The long-run ARDL estimates indicate that air transport and financial development exert negative but statistically insignificant effects on economic growth. However, the NARDL results reveal the existence of nonlinear relationships. Positive shocks to air transport have a positive and statistically significant impact on economic growth, while negative shocks also generate a positive but statistically insignificant effect. Regarding financial development, positive shocks contribute significantly to economic growth, whereas negative shocks have a significant adverse effect. This finding confirms that expansions and contractions in financial development do not have identical consequences for economic performance in South Korea.

The short-run ARDL results show that both air transport and financial development have negative effects on economic growth, although only the negative effect of financial development is statistically significant. In contrast, the NARDL estimates demonstrate significant asymmetric responses. Positive shocks to air transport stimulate economic growth, while negative shocks produce a positive but weaker effect. Furthermore, positive shocks to financial development enhance economic growth, whereas negative shocks reduce economic growth significantly. These findings indicate that South Korea's economic performance is highly responsive to financial development shocks, particularly contractionary shocks that may restrict credit availability and investment activities.

Based on these findings, policymakers in South Korea should focus on improving the efficiency and stability of the financial system by implementing effective credit allocation policies and preventing excessive fluctuations in financial conditions. In addition, strengthening the air transport sector through infrastructure development, technological advancement, and improved connectivity can contribute to sustaining economic growth.

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Symmetric and Asymmetric Impact of Trade openness, financial development on Economic Growth in Ireland: New Evidence

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Abstract

This study aims to explore the symmetric and asymmetric impact of trade openness and financial development on Irish economic growth. Annual data covering the period 1981–2023 were used, using both linear autoregressive distributed lag ARDL and nonlinear autoregressive distributed lag NARDL. The results of the ARDL test for the symmetric impact in the long and short run showed that trade openness and financial development have a negative impact on economic growth. Regarding the asymmetric impact, the results of the NARDL test showed that the impact of positive and negative shocks in trade openness on economic growth in the long and short runs is asymmetric, positive shock has positive impact on economic growth in the long run, but negative impact in the short run, while negative shock has negative impact in the long and short run. The positive and negative shocks in financial development in the long and short run are symmetric, meaning that positive shocks are equivalent to negative shocks.

Keywords: Financial development, Trade Openness, Economic growth, NARDL, Ireland

JEL classification : C10, F43, G21

Introduction

Trade openness and financial development represent two of the most important macroeconomic variables that have directly contributed to economic growth in recent years. Trade openness is defined as the level of a country's engagement in international trade through imports and exports. It has been identified as a crucial driver of economic growth, promoting competitiveness, innovation, and specialization (Krueger, 1978). Export-focused strategies have been essential for numerous developed and developing countries, as demonstrated by the economic successes of East Asian countries such as South Korea and Singapore (Rodrik, 1999). By integrating with global markets, these nations have benefited from economies of scale, access to new technologies, and improved productivity. Nonetheless, trade openness can also bring difficulties, such as heightened reliance on global demand and vulnerability to external shocks, illustrated during the global financial crisis (Baldwin, 1997). One of the earliest frameworks originates from Ricardian trade theory, which highlights the concept of comparative advantage. Ricardo (1817) argued that trade enables countries to focus on goods in which they possess relative efficiency, resulting in mutual benefits and economic growth. This idea was later elaborated by the Heckscher–Ohlin model, which underscores the influence of factor endowments on trade patterns and their impact on economic development (Ohlin, 1933). These theories established the groundwork for comprehending how trade openness stimulates growth by enhancing resource allocation, boosting efficiency, and facilitating technology transfer.

Current technological advancements, coupled with accelerated trade liberalization, have led to significant developments in the financial sector. Financial development and stability play a significant role in the economic growth of countries. Through financial development, the financial sector expands, economic liquidity has increased, financial innovations exhibit, and increased growth in the financial sector. The function of the financial sector is summarized as an intermediary that redistributes resources between savers and investors. The former invests their money with confidence, while the latter obtains the financial resources necessary for appropriate investment.

Schumpeter (1912), one of the initial pioneers, underscored the significance of finance in promoting growth. Similarly, Patrick (1966) introduced two new ideas that emphasize the conditions on both the demand and supply sides: the demand-following and supply-leading hypotheses. The former suggests that demand in the real sector drives the creation of financial services, while the latter posits that supply within the financial sector propels the advancement of the real sector. According to Rioja and Valev (2011), the financial sector (including banking and stock markets) has a positive effect on economic growth in middle and high-income countries, but a negative impact on lower-income nations. Demetriades and Hussein (1996) provide evidence that finance is a primary factor in the economic growth process. They also found that in most countries, the causality runs both ways, although, in some instances, financial development is a consequence of economic growth.

Despite the significant challenges faced by the Irish economy during the 1980s, the economic policy pursued by the Irish government during the 1990s focused on a knowledge-based economy, information and Communication Technology (ICT), smart industries, enhanced exports and development the transportation sector, these successes have been led to achieve remarkable economic growth. In 1981, GDP was \$20.67 billion, and with noteworthy economic growth, it reached \$551.39 billion in 2023.

Ireland is considered one of the most open countries in the field of international trade, with Irish trade accounting for approximately 237.21% of the GDP in 2023. Figure 1 shows the trend of growth rate of GDP and trade openness over the period 1982-2023. It is noted that there is an inverse trend between increasing trade openness and economic growth. This is primarily due to the significant increase in global competition, trade shocks, and the emergence new economic players such as China. The average means for both economic growth and trade openness were 0.09 and 0.02, confirming that trade openness has a modest impact on economic growth in Ireland.

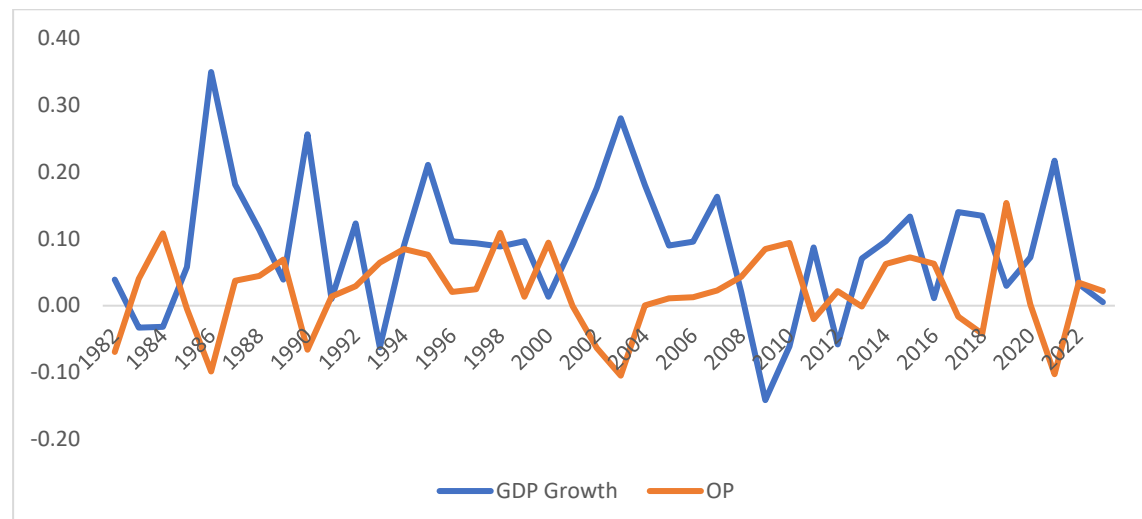


Figure 1. The growth rate in GDP and trade openness in Ireland (1982-2023)

Source: World Bank.

Figure 2 indicates that the growth rate of GDP and financial development in Ireland move in opposite directions. In the case where financial development decreases, it leads to an increase in economic growth, and vice versa. The average means of the growth rate of GDP and financial development during the period 1982-2023 is (0.09) and (-0.001) respectively, which confirms that financial development does not contribute to economic growth.

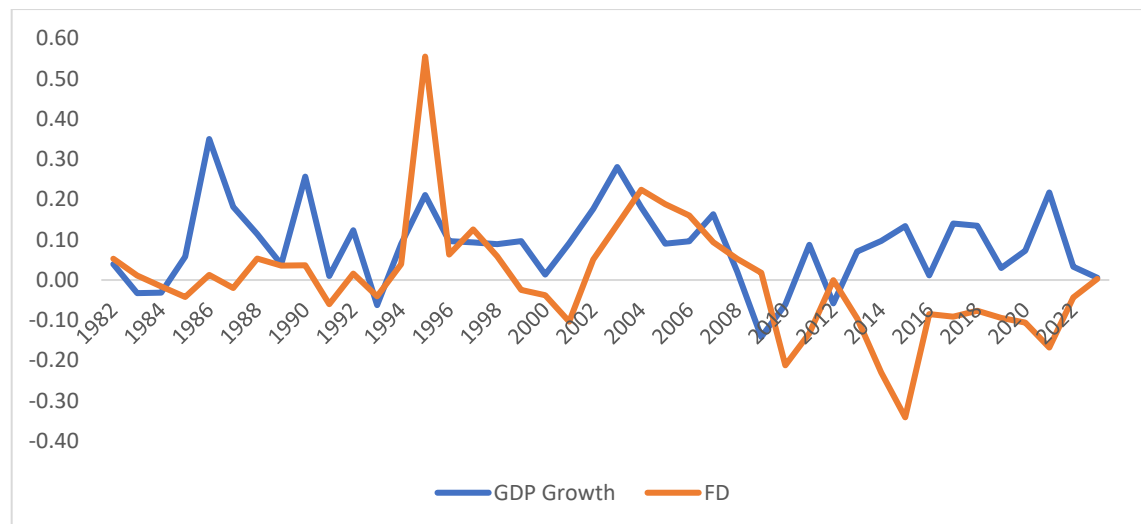


Figure 2. The growth rate in GDP and Financial development in Ireland (1982-2023)

Source: World Bank.

Literature review

Many scholars have studied the impact of both trade openness and financial development on economic growth in developing and developed countries, as unstable international economic conditions contribute to positive and negative shocks in macroeconomic variables, especially in the financial and external sectors.

Sriyana and Afandi (2020) explored the impact of trade openness alongside other economic factors such as foreign direct investment, gross capital formation, and human capital on economic growth in certain ASEAN countries. Annual time series data for the period of 1970–2017 were employed, the empirical NARDL models account for the asymmetric effects of trade openness on economic growth in Indonesia, the Philippines, Thailand, and Singapore. In contrast, Malaysia exhibits symmetric effects in both short- and long-run models, while the Philippines, Thailand, and Singapore present asymmetric effects in the long run and symmetric in the short run. In Indonesia, however, the influence of trade openness is asymmetric in the short term and symmetric over the long term. Moreover, the findings indicate that trade openness has a net positive effect on economic growth solely in the Philippines and Singapore.

Mallick and Behera (2020) examined the long-term equilibrium relationship between economic growth and trade openness in India from 1960 to 2018 using the asymmetric error-correction model with threshold cointegration. To assess the robustness of trade openness's impact on economic growth across different regimes, the full sample period was divided into two sub-periods, namely the pre-trade reforms phase from 1960 to 1990 and the post-trade reforms phase from 1991 to 2018. Their study confirms the presence of asymmetric cointegration between economic growth and trade openness in India throughout the evaluated period and across distinct sub-periods. The derived asymmetric error-correction model reveals varying adjustment speeds in trade openness in response to positive and negative economic growth shocks in the short term. Specifically, during the pre-reform period, deviations from the long-run equilibrium resulting from an increase in economic growth

exhibit a slower adjustment speed compared to deviations caused by a decrease in economic growth in India.

Kaushal and Pathak (2015) indicated that there exists a short-term connection between GDP, trade openness, and financial development in India from 1991 to 2013. Their empirical findings suggest that financial development does not have an impact on GDP, as indicated by the causality test and VAR analysis. Adamopoulos (2013) investigated the connection between financial development and economic growth in Ireland from 1965 to 2011. A vector error correction model was applied, based on Johansen cointegration analysis and stationarity testing. The Granger causality method was subsequently utilized to determine the direction of causality among the variables studied. The empirical results revealed a bilateral causal relationship between economic growth and industrial production, while a unidirectional causality from economic growth to credit market development was observed. Additionally, development in the stock market was found to cause economic growth and industrial production.

Rahman et al. (2015) explored the connection between financial development, international trade, and economic growth in Australia from 1965 to 2010. They utilized the autoregressive distributed lag (ARDL) bounds testing method to analyze the long-term relationship among the variables. The findings indicate a long-run relationship among these factors. Financial development, international trade, and capital are identified as key contributors to economic growth in both the short and long terms.

Ductor and Grechvna (2015) explored the relationship between real sector output and financial development, focusing on how GDP influences this relationship by analyzing panel data from a variety of developed and developing nations. The findings indicate that the impact of financial development on GDP is significantly influenced by net credit to key industries, and this effect turns negative without a corresponding increase in real output. Isik et al. (2017) identified both unidirectional and bidirectional relationships between financial development, international trade, and GDP in Greece over the period from 1970 to 2017, utilizing an unrestricted error correction model for the ARDL approach.

Shahbaz et al. (2020) explored the influence of financial development on economic growth, highlighting asymmetric effects and financial efficiency among the top 10 financially developed countries. They utilized annual data spanning from 1971 to 2016. A three-regime threshold autoregressive distributed lags (TARDL) model was created to accommodate their analysis. The empirical results indicated the presence of threshold asymmetric co-integration between the variables. Specifically, in the upper regime, financial development promotes economic growth in Singapore but negatively affects economic growth in Finland. In the middle regime, financial development enhances economic growth in both Australia and Singapore. Conversely, in the lower regime, financial development negatively impacts economic growth in the US, Malaysia, and Singapore. Additionally, trade openness has a favorable long-term effect on economic growth in Canada, South Africa, Australia, Malaysia, New Zealand, Singapore, Finland, and Norway.

Asteriou et al. (2023) investigated the relationship between finance and economic growth, as well as the performance of the financial system, which was measured through financial depth, accessibility, and efficiency across both financial institutions and stock markets. The analysis utilized data from a panel of 26 European Union countries covering the period from 1990 to 2020, employing GMM panel estimation. The findings indicate that during normal circumstances, the relationship between finance and growth, alongside the stock market's

role, is significantly important, whereas during periods of stress, this relationship loses its significance. Alexiou et al. (2018) discovered that from 1998 to 2014, a rise in credit flows had a negative impact on the economies of 34 European and Commonwealth of Independent States countries, while the previously observed positive influence of money supply on growth before the Global Financial Crisis was not supported in advanced economies, unlike in developing nations. Seti et al. (2025) analyzed the effects of financial and trade openness on economic growth in ten emerging and developing countries from 1970 to 2023. Their study utilized a dynamic panel generalized method of moments (GMM) model, and the results showed that both financial and trade openness have a positive effect on economic growth.

Ho et al. (2021) investigated the causal relationship between financial development and economic growth through trade openness in six leading ASEAN countries (Indonesia, the Philippines, Malaysia, Singapore, Thailand, and Vietnam). This research utilized panel data spanning 25 years from 1995 to 2019 for these nations, employing both the fixed effect model (FEM) and the random effect model (REM). The results revealed that trade openness is positively correlated with growth, while financial development showed a positive but insignificant relationship with growth. Liu and Hsu (2006) investigated the connection between financial development and growth sources for three Asian economies: Taiwan, Korea, and Japan. The data analyzed for these countries consists of quarterly information from 1981:1 to 2001:3. The selection of 1981:1 as the starting point was influenced by the commencement of market liberalization in Korea and Taiwan that year, as well as data availability constraints. Using the generalized method of moments (GMM) and principal component analysis, the result indicated that the financial aggregate had a beneficial impact on Taiwan's economy but adversely affected the other two countries; stock market development positively influenced Taiwan's economic growth.

Ahfer and Inoue (2014) explored the long-term relationship between financial development, stock market growth, and economic advancement in Japan. Quarterly data for the Japanese economy for the period 1957 to 2011. Johansen Co-integration Technique and Vector Error Correction Model were employed to assess these relationships. Their findings indicate that there exists a long-run equilibrium relationship between financial development, stock market growth, and economic growth in Japan, confirming that both financial and stock market developments foster economic growth, but no causal relationship from economic growth to financial or stock market development was found. Additional analyses revealed that although bank-based financial development and stock market growth promote economic growth, stock market development has been particularly significant for Japan's economic progress since 1974.

Jaberi et al. (2015) investigated how financial development and symmetric information influence economic growth across all European Union members. A Pooled Data approach was utilized from 2000 to 2012. The results indicate that financial development alongside symmetric information contributes to a higher rate of economic growth within the European Union. Akinci et al. (2014) examined the relationship between financial development and economic growth in OECD countries using unbalanced panel cointegration and causality analysis from 1980 to 2011. The findings of the Pedroni and Kao Cointegration Analysis confirm a long-term relationship between financial development and economic growth. The Granger Causality Analysis results suggest a unidirectional causal relationship running from economic growth to the three financial development proxy variables, while a bidirectional relationship is identified between the broad money measure and economic growth. Therefore, the demand-following phenomenon appears to be prevailing.

Chung et al. (2016) analyzed the causal interactions between financial development, liberalization, and economic growth through the channel of technological innovation in five Southeast Asian countries from 1980 to 2012, utilizing a fully modified ordinary least squares estimation technique. They discovered that advancements in technology are primarily driven by the strengthening of the financial system and financial liberalization, rather than by fluctuations in a country's market capitalization. Additionally, they observed a negative impact from financial openness and a positive effect from financial deregulation.

Currently, many developed countries face numerous challenges, particularly due to US trade policies, which can lead to significant shocks to economic growth. This study attempts to explore the symmetric and asymmetric impact of trade openness and financial development on Irish economic growth.

Model specification and methodology

3.1 Model specification

This study examines the relations between economic growth and trade openness, financial development. Following King and Levine (1993), Asghar and Hussain (2014), Belazreg and Mtar (2019), Shahbaz et al. (2020), Rafindadi and Ozturk (2017), and Menyah *et al.* (2014). The study model is based on extended traditional production function as follows:

$$GDP = Af(K, L) \quad (1)$$

By extended equation (1) through insert Trade openness (OP) and financial development (FD).

$$GDP = f(K, L, OP, FD) \quad (2)$$

Where, *GDP*: proxy of Economic growth; *K*; gross fixed capital formation (real domestic investment); *L*: Labor force; *FD* : financial development (Domestic credit to private sector), *OP*: trade openness.

By taking natural logarithm of equation (2), it becomes as:

$$LGDP_t = \beta_0 + \beta_1 LOP_t + \beta_2 LFD_t + \beta_3 LK_t + \beta_4 LL_t + \varepsilon_t \quad (3)$$

In this study, empirical specification is an econometric representation of the linear and non-linear relationship between *OP*, *FD*, *K*, *L* and *GDP* in the context of short-run and long-run dynamics.

3.2 Methodology

To test the symmetric and asymmetric relationship between trade openness, financial development and economic growth, linear autoregressive distributed lag (ARDL) which was developed by Pesaran *et al.* (2001), and nonlinear autoregressive distributed lag NARDL which was advanced by Shin *et al.* (2014). In this context, ARDL bounds test approach was used to estimate the symmetric the long-run and short-run relationship between *OP*, *FD*, *K*, *L* and *GDP*. Based on Equation (3), the ARDL model estimates the effect of independent variables on the GDP growth within the framework of short-run and long-run dynamics as follows:

$$\Delta LGDP_t = \beta_0 + \beta_1 GDP_{t-1} + \beta_2 LOP_{t-1} + \beta_3 LFD_{t-1} + \beta_4 LK_{t-1} + \beta_5 LL_{t-1} + \sum_{i=1}^q \gamma_1 \Delta GDP_{t-i} + \sum_{i=1}^q \gamma_2 \Delta LOP_{t-i} + \sum_{i=1}^q \gamma_3 \Delta LFD_{t-i} + \sum_{i=1}^q \gamma_4 \Delta LK_{t-i} + \sum_{i=1}^q \gamma_5 \Delta LL_{t-i} + \theta ECM_{t-1} + \varepsilon_t \quad (4)$$

Where q representing the lag length of the series, Δ as the first difference operator, and θ as the coefficient of the ECM. $\beta_1 - \beta_5$ represent the long run coefficients, $\gamma_1 - \gamma_5$ represent the short run coefficients.

To investigate the positive and negative shock in trade openness, financial development and its impacts on economic growth, the nonlinear autoregressive distributed lag (NARDL) methodology is considered a brilliant econometric estimation technique for discovering the asymmetric impacts. Several reasons support employing the NARDL method, specifically its usefulness in capturing the intricate dynamics that define these economic connections. The main validation for utilizing the NARDL method lies in its ability to discover asymmetric relationships that traditional linear models may struggle to adequately illustrate, as these conventional models assume uniform responses to changes in independent variables. In contrast, the NARDL method simplifies separate estimation of both positive and negative shocks, allowing for a more nuanced understanding of how economic variables respond to both increases and decreases in growth interventions. Furthermore, a notable advantage of employing the NARDL framework is its ability to model short-term dynamics alongside long-term associations within a single framework. This feature allows for a comprehensive examination of both immediate and enduring effects, providing a holistic view of the temporal dynamics of economic growth. Furthermore, the NARDL approach excels at addressing the nonlinearities found in economic relationships. Given the observed nonlinear effects, a modeling technique capable of accommodating the complexities in the interactions among trade openness, financial development, and economic growth is essential. The NARDL model's capacity to integrate nonlinear changes confirms a more accurate and realistic portrayal of these relationships, thereby filling a gap often neglected in linear analyses. Lastly, the NARDL method's significance is further improved by its robustness to the integration properties of variables. As noted by Shin et al. (2014). According to Boehlke et al. (2017), the nonlinear growth pattern of Irish GDP was more plausible based on empirical evaluations than the linear alternative. Equation (2) can be reformulated within the NARDL framework as follows:

$$\begin{aligned} \ln GDP_t = & a_0 + a_1 \ln OP_t^+ + a_2 \ln OP_t^- + a_3 \ln FD_t^+ + a_4 \ln FD_t^- + a_5 \ln K_t + \\ & + a_6 \ln L_t + \varepsilon_t \end{aligned} \quad (5)$$

In order to examine the positive and negative shock impact of trade openness and financial development on economic growth, the changes in the partial sum can be portrayed as follow:

$$OP_t^+ = \sum_{i=1}^t \Delta OP_i^+ = \sum_{i=1}^t \max(\Delta OP_i, 0) \quad \text{Positive shock} \quad (6)$$

$$OP_t^- = \sum_{i=1}^t \Delta OP_i^- = \sum_{i=1}^t \min(\Delta OP_i, 0) \quad \text{negative shock} \quad (7)$$

$$FD_t^+ = \sum_{i=1}^t \Delta FD_i^+ = \sum_{i=1}^t \max(\Delta FD_i, 0) \quad \text{positive shock} \quad (8)$$

$$FD_t^- = \sum_{i=1}^t \Delta FD_i^- = \sum_{i=1}^t \min(\Delta FD_i, 0) \quad \text{negative shock} \quad (9)$$

The NARDL model is utilized to explore how fluctuations in shocks, including both positive and negative changes in independent variables, impact time-series dependent variables (Neog and Yadava, 2020). Due to its accurate and reliable outcomes when the variables are in level $I(0)$, the first difference $I(1)$, or a combination of $I(0)$ and $I(1)$, NARDL is a commonly applied technique. It also differentiates between the short-run and long-run impacts of independent variables on the dependent variable. According to the critical bounds established by Pesaran *et al.* (2001), a long-term relationship among the variables is identified when the calculated F-statistics exceed the upper bound's critical value at a 5% significance level. By integrating

equations 6, 7, 8, and 9 adhering to the econometric methodology of Shin *et al.* (2014) and Villanthenkodath *et al.* (2021), NARDL model estimation for both long-run and short-run effects as outlined:

$$\begin{aligned} \Delta \ln GDP_t = & \beta_0 + \beta_1 \ln GDP_{t-1} + \beta_2 \ln OP^+_{t-1} + \beta_3 \ln OP^-_{t-1} + \\ & \beta_4 \ln FD^+_{t-1} + \beta_5 \ln FD^-_{t-1} + \beta_6 \ln K_{t-1} + \beta_7 \ln L_{t-1} + \\ & \sum_{i=1}^j \delta_1 \Delta \ln GDP_{t-i} + \sum_{i=0}^k (\delta_2^+ \Delta \ln OP_i^+ + \delta_3^- \Delta \ln OP_i^-) + \sum_{i=0}^m (\delta_4^+ \Delta \ln FD_i^+ + \\ & \delta_5^- \Delta \ln FD_i^-) + \sum_{i=0}^n \delta_6 \Delta \ln K_{t-i} + \sum_{i=0}^l \delta_7 \Delta \ln L_{t-i} + \varphi ECM_{t-1} + \varepsilon_t \end{aligned} \quad (9)$$

Where, $\beta_1 - \beta_7$ long run impacts, $\alpha_1 - \alpha_6$ long run impacts as mentioned in equation 5, $\alpha_1 = -\beta_2/\beta_1$; $\alpha_2 = -\beta_3/\beta_1$ displays the long run impacts of positive and negative shock in the trade openness on economic growth, $\alpha_4 = -\beta_4/\beta_1$; $\alpha_5 = -\beta_5/\beta_1$ presents the long run impacts of positive and negative shock in the financial development on economic growth, j, k, m, n, l , are lag orders, $\delta_1 - \delta_6$ short run impacts, $\sum_{i=0}^k \delta_2^+$ measure the impact of an increase in trade openness on economic growth in the short term, $\sum_{i=0}^k \delta_3^-$ measure the impact of a decrease in trade openness on economic growth in the short term. $\sum_{i=0}^m \delta_4^+$ measure the impact of an increase in financial development on economic growth in the short term, $\sum_{i=0}^m \delta_5^-$ measure the impact of a decrease in financial development on economic growth in the short term. Δ denotes difference operator; and ε_t is the white noise term.

The impact of dynamic asymmetric multiplier on the variables can be stated as follows:

$$m(OP)_h^+ = \sum_{j=0}^h \frac{\partial y_{t+j}}{\partial OP_{t-1}^+} = m(OP)_h^- = \sum_{j=0}^h \frac{\partial y_{t+j}}{\partial OP_{t-1}^-}, h = 0, 1, 2 \dots \quad (10)$$

$$m(FD)_h^+ = \sum_{j=0}^h \frac{\partial y_{t+j}}{\partial FD_{t-1}^+} = m(FD)_h^- = \sum_{j=0}^h \frac{\partial y_{t+j}}{\partial FD_{t-1}^-}, h = 0, 1, 2 \dots \quad (11)$$

Kowing that, as $h \rightarrow \infty$, $m(OP)_h^+ \rightarrow a_1$, and $m(OP)_h^- \rightarrow a_2$.

$$m(FD)_h^+ \rightarrow a_3, \text{ and } m(FD)_h^- \rightarrow a_4.$$

By utilizing these dynamic multipliers, the endogenous variable reacts differently to positive and negative changes in the exogenous variable. When there is a change to the model, the estimated multipliers enable us to track the dynamic adjustment between the variables from the initial equilibrium to their new equilibrium following the change.

3.3 Data

To achieve econometric analysis, Annual time series data from 1981 to 2023 was used. Data regarding GDP, trade openness, financial development, gross fixed capital formation, and labor forces obtained from the World Development Indicators (WDI). The descriptive statistics variables are shown in Table 1. All of the series' standard deviations were found to be relatively low, demonstrating little data variability. Furthermore, all series had a normal distribution, according to the Jarque-Bera coefficient.

Table 1. Descriptive statistics

	LGDP	LOP	LFD	LK	LL
Mean	25.48946	5.026987	4.119238	24.00528	7.545582

Median	25.57994	5.033028	3.880945	24.13573	7.600713
Maximum	27.03572	5.521895	5.131377	26.10169	7.937194
Minimum	23.72432	4.542972	3.264232	22.10976	7.148031
Std. Dev.	1.038956	0.303342	0.529578	1.178706	0.239517
Skewness	-0.266028	-0.011796	0.367592	-0.062971	-0.371733
Kurtosis	1.809650	1.764280	2.022638	1.728064	1.820815
Jarque-Bera	3.045863	2.736878	2.679851	2.927013	3.481601
Probability	0.218072	0.254504	0.261865	0.231423	0.175380

Empirical results

In Table 2, the findings of the optimal lag selection are displayed. Identifying the best lag in the ARDL model aims to address the issue of autocorrelation within the model system by treating the lag in endogenous variables as an exogenous variable. The optimal lag determination is based on the likelihood ratio (LR), final prediction error (FPE), AIC, Schwarz information criterion (SIC), and Hannan–Quin criterion (HQ) values. As indicated in Table 2, the chosen lag is lag 1, as the optimal lag implies that all variables not only influence each other in the same period but also in the preceding one period.

Table 2. Lag selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	35.07037	NA	1.53e-07	-1.503519	-1.292409	-1.427188
1	263.6567	388.5968*	5.87e-12*	-11.68283*	-10.41618*	-11.22485*
2	281.6500	26.09022	8.86e-12	-11.33250	-9.010289	-10.49286
3	293.3315	14.01789	2.03e-11	-10.66658	-7.288818	-9.445285

Before engaging in a cointegration test, it is essential to perform unit root tests to assess the stationarity characteristics of the parameters. This step is vital as it aids in selecting an appropriate test for the subsequent phase of the study and identifies the type of stationarity of the parameters being analyzed. Two-unit root testing methods were implemented in this study: Augmented Dickey-Fuller (Dickey and Fuller, 1979), and Phillips-Perron (Perron, 1989). As shown in Table 3, all parameters evaluated displayed stability at the level $I(0)$ or after the first difference $I(1)$. This indicates that cointegration and the ARDL estimator can be utilized with the data.

Table 3. The results of unit root tests

Variables	ADF		PP	
	At level	First difference	At level	First difference
L(GDP)	-0.823206	-4.907232***	-0.801525	-4.817488***
L (OP)	-0.511877	-5.846246***	-0.456710	-5.918830***
L (FD)	-1.206503	-3.387977**	-0.971635	-3.363599**
L (L)	-0.483313	-5.693476***	-0.446975	-5.693476***
L (K)	-0.448339	-4.830611***	-0.527135	-4.779780***

*, ** and ***, 1%, 5% and 10%

symmetric ARDL estimation

The dataset's stationarity can be assessed based on the results from the unit root tests. An ARDL bounds test was conducted to evaluate whether a cointegration relationship exists among the parameters utilized. The results of the cointegration analysis are presented in Table 4. The computed F-statistic for cointegration (11.237) exceeds the maximum upper bounds.

Table 4. ARDL bounds test results

Null hypothesis: No degree of relationship			
	Sig.	I(0	I(1)
F- value (11.237)	10%	2.2	3.09
K 4	5%	2.56	3.49
	2.5%	2.88	3.87
	1%	3.29	4.37

*, ** and ***, 1%, 5% and 10%

The results of the test of the symmetric effect of trade openness and financial development in the long and short term on economic growth shown in Table 5, indicate that economic growth is negatively affected by the increase in trade openness and financial development, while the labor force and fixed capital formation have a positive effect.

The ECM value mirrors the speed at which the system moves from a temporary balance to a state of permanent stability. Both the coefficient and the derived ECM are negative at the 1% significance level. According to the ECM value, short-term deviations from the long-term equilibrium path are generally adjusted by an average of 6.44 %. The significantly negative

ECM coefficient indicates that any long-term disparities among the model variables will adjust or align with the long-term equilibrium.

Table 5. ARDL long and short run results

Independent Variables	Long run		Short run	
	coefficients	Prob.	coefficients	Prob.
LOP	-0.392256	0.8222	-0.970599	0.000
LFD	-0.153839	0.6814	-0.009917	0.6528
LL	2.053883	0.5285	0.132396	0.6627
LK	0.469512	0.4390	0.238680	0.000
C	2.535416	0.8319		
ECM			-0.064462	0.000

*, ** and ***, 1%, 5% and 10%.

Asymmetric NARDL estimation

To achieve the NARDL estimation, the bound test for cointegration was made. The F-statistic value is 3.417, these values exceeded the upper bound $I(1)$, as shown in Table 6. Consequently, rejecting the null hypothesis of no level relationship. This established the existence of a long-run asymmetric relationship between economic growth and explanatory variables.

Table 6. NARDL bounds test results

Null hypothesis: No degree of relationship			
	Sig.	$I(0)$	$I(1)$
	10%	1.99	2.94
F-value (3.417)	5%	2.27	3.28
K 6	2.5%	2.55	3.61
	1%	2.88	3.99

*, ** and ***, 1%, 5% and 10%

Regarding the asymmetric effect of positive and negative shocks in trade openness and financial development in the long run, the result reveals that in positive shock a 1% increase in openness contributes to economic growth by 0.61%, but insignificantly. In negative shock a 1% decrease in trade openness leads to a negative effect, reducing economic growth by 2.53%, and insignificantly. Moreover, the NARDL results show that a positive shock in financial

development decreases economic growth by 0.11%. A negative shock in financial development contributes to a 0.16% increase in economic growth. The results also show that the labor force and fixed capital formation have a positive effect on Irish economic growth.

Concerning the impact of positive and negative shocks in trade openness and financial development on economic growth in the short term, the results show that a 1% increase in trade openness resulting from a positive shock leads to a 0.63% decrease in economic growth, while a 1% decrease in trade openness accompanied by a negative shock leads to a 1.48% decrease in economic growth. A 1% positive shock in financial development leads to a 0.24% increase in economic growth, while a 1% decrease in financial development resulting from a negative shock leads to a 0.23% decrease in economic growth. Finally, it was also shown that the labor force and fixed capital formation have a positive impact on economic growth.

Concerning the error correction coefficient (ECM), the test results showed that the error correction coefficient value is 28.24, and is statistically significant, meaning that short-term deviations from the long-term equilibrium path are generally adjusted by an average of 28.24% each year, respectively. The significantly negative ECM coefficient indicates that any long-term disparities among the model variables will adjust or align with the long-term equilibrium.

Table 7. NARDL long and short run results

Independent Variables	Long run		Short run	
	coefficients	Prob.	coefficients	Prob.
LOP_POS	0.613424	0.2141	-0.638650	0.0007***
LOP_NEG	-2.538795	0.0027***	-1.481472	0.0000***
LFD_POS	-0.112366	0.6111	0.241672	0.0116**
LFD_NEG	0.161762	0.2564	-0.231704	0.0041***
LK	0.395581	0.0163**	0.204921	0.0000***
LL	0.115271	0.8951	0.032559	0.8977
C	14.19475	0.0132		
ECM			-0.282452	0.0000***

*, ** and ***, 1%, 5% and 10%.

The asymmetry Wald test essentially represents a test of whether the coefficients are equal or not, a test of whether the positive and negative shocks of trade openness on economic growth have different magnitudes of effect in the long and short run, however, financial development on economic growth have the same magnitude of effect in the long and short run. The results are shown in Table 8.

Table 8. Asymmetry tests

	W_{LR}			W_{SR}		
	F-statistic	Prob.	Result	F-statistic	Prob.	Result
OP	9.804813	0.0040	asymmetric	49.68068	0.000	asymmetric
FD	0.791465	0.3812	symmetric	0.004351	0.9479	symmetric

Where, W_{LR} (Wald long-run result), W_{SR} (Wald short-run result).

Figure 3 illustrates the existence of a negative relationship between trade openness and economic growth. The solid black line shows the positive impact of trade openness on GDP. The effect of a negative shock in trade openness is found to dominate that of a positive shock. The NARDL multiplier effects figure demonstrates the asymmetries between the positive and negative shocks in trade openness and economic growth.

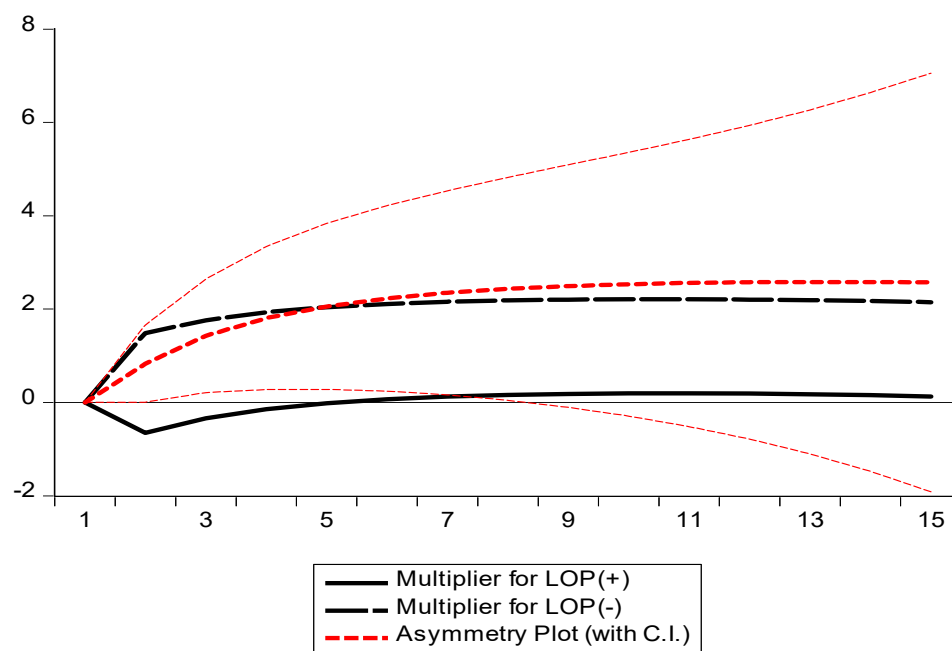


Figure 3. NARDL multiplier of trade openness and response of economic growth

Figure 4 shows the asymmetric NARDL dynamic multiplier effects, which highlight the impact of both positive and negative shocks in financial development on economic growth. The solid black line shows the positive impact of financial development on GDP, whereas the dotted black line shows the negative effect of financial development on Irish economic growth.

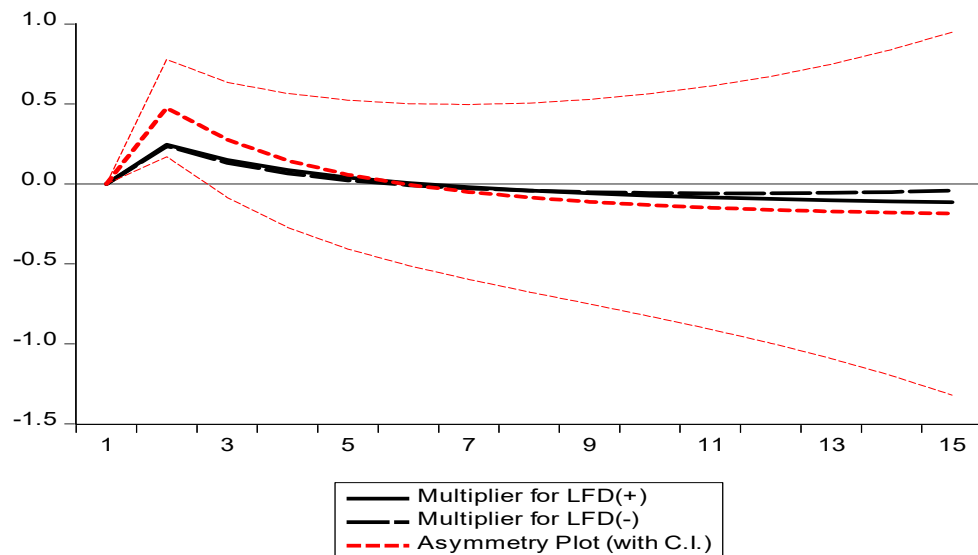


Figure 4. NARDL multiplier of financial development and response of economic growth

Diagnostic tests

According to Table 9, the model is not affected by any problems as indicated by several diagnostic tests performed before the final implementation of the asymmetric ARDL model. The p-values for the Jarque-Bera test, LM test, Heteroskedasticity Test, and Ramsey Reset test. The results of the Jarque-Bera test confirm that the residuals are normally distributed, and our model does not exhibit problems with serial correlation or heteroscedasticity. Furthermore, the Ramsey RESET value is also statistically insignificant, which indicates that our model is appropriately specified.

Table 9: ARDL and NARDL results of diagnostic tests

Diagnostic tests	ARDL		NARDL		Decision
	Coefficient	Prob.	Coefficient	Prob.	
Jarque-Bera test	0.091	0.955	0.799	0.670	Residuals are normally distributed
Breusch-Godfrey Serial Correlation LM Test:	1.632	0.2115	0.354	0.705	No serial correlation exists
Heteroskedasticity Test: Breusch-Pagan-Godfrey	0.110	0.9973	1.105	0.394	No heteroscedasticity exists
Ramsey Reset test	2.534	0.1210	2.915	0.100	The model is properly specified

Conclusion

Economic growth is significantly affected by internal and external shocks of international trade and financial sector. Today, many countries are attempting to understand the impact of positive and negative shocks of the economic variables on economic growth. This study attempts to shed light on the symmetric and asymmetric impact of trade openness and financial development on Irish economic growth. To achieve the study's objective, annual data spanning the period 1981-2023 were used. The symmetry results showed that trade openness and financial development have a negative impact on Irish economic growth in both the long and short term. Limited trade openness policy may reduce imports, thus preserving cash flows within the domestic economy, as well as, rationing credit to the private sector contributes to stimulating investments toward productive sectors, thus achieving economic growth. Regarding the asymmetric effect of trade openness and financial development, the results of the NARDL test showed that the positive and negative impact of shocks in trade openness on economic growth are asymmetric and that negative shocks outweigh positive shocks in the long and short runs.

Concerning the positive and negative shocks in financial development in the long and short run the results show that the impact on economic growth is symmetric. These results are of great importance to Irish trade policymakers.

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The Impact of Innovation on High Technology Exports in South Korea, Germany and United States: New Evidence

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Abstract

This study aimed to test the impact of innovation on high-tech exports in South Korea, Germany, and the United States. Annual data were tested over the period 1988-2023. Autoregressive distributed lag (ARDL) was used, the results indicated the existence of cointegration between the study variables for the three countries. The long-run outcome showed that high-tech exports in both South Korea and Germany were positively significant affected by patents. In the short run, high-tech exports were positively significant affected by patents in South Korea, Germany, and the United States. Surprisingly, research and development (R&D) spending affects South Korea's exports, but it is not statistically significant in the short run, despite the high spending rates. Conversely, high-tech exports in Germany and the United States were positively and statistically significant affected by R&D spending. Finally, the results showed that both foreign investment and gross fixed capital formation affect high-tech exports.

Keywords: Innovation, High Technology, Exports, South Korea, Germany, USA

JEL Classification: M16, O30, O31, O38

Introduction

Endogenous growth theory suggests that the adaptation of technology, along with innovation and imitation, are crucial elements for a nation's technological advancement (Romer, 1990). This advancement plays a role in an economy's growth by influencing its competitive stance in international markets. Vernon (1966) highlights the significance of technological factors in global competition, which stem from the unique advantages of countries, leading to the creation of new products and processes. Research often treats innovation as an external factor and posits that it influences a country's export efficiency (Krugman, 1979; Posner, 1961).

In recent years, the world has witnessed tremendous developments in the field of information and communications flows, accompanied by significant advances in technology. The collapse of international borders in the face of growing international trade and the emergence of global homogeneity of tastes has contributed to a transformation in the global economy. Innovation has become a feature of everyday life, and modern technology has become a primary goal of major economies. The forces of globalization have enhanced global innovation by creating high-tech products in the home country and redistributing them to international markets (Leonidou and Katsikeas 2010).

Traditionally, it has been assumed that the export structure of countries relied heavily on the proportion of ownership of production factors. This has led developed countries to specialize in high-tech products. Specialization leads to efficient resource management, which is reflected in competitiveness in terms of price and quality. Thus, innovation contributes to enhancing competitive advantage by reducing costs and developing new products with high efficiency that attract new customers. High-tech exports are characterized by their dynamic component, which makes innovation highly linked to trade activities especially in advanced technology equipment's. This creates a bidirectional relationship between innovation and technology exports (Smallbone et al. 2022).

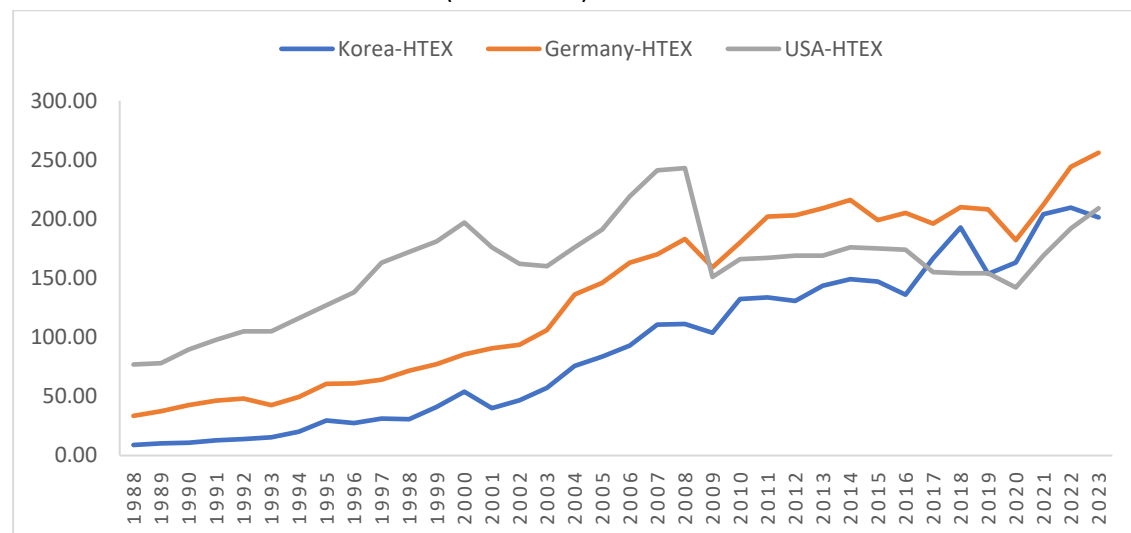
Technological innovation can be described as a nation's "absorption capacity"—the capability to implement outside information by creating new products and processes that are essential for global trade and economic growth (Zahra and George, 2002). Innovative activities are scientific, technological, financial, and institutional fields that contribute to changing traditional production patterns and imbuing the economy with an innovative character. Patents are the fruit of innovation and an indicator of the performance of development processes in the economy. They reflect the success of allocating research and development within highly productive activities (Crosby, 2000).

Innovation can provide a competitive advantage by focusing on costs, by developing a new, more efficient production process, and/or by building differentiation through product innovations, which allow companies to customize their products to customer requirements,

or develop higher-quality products. (Lopez Rodriguez and Garcia Rodriguez, 2005). High-tech exports contribute to long-term economic growth sustainability compared to traditional industries. This is because high-tech products tend to be income-elastic, leading to the creation of new demand, replacing old ones, and accelerating international trade (Montobbio & Rampa, 2005).

Global high-tech exports reached approximately \$1.969 trillion in 2007, with South Korea, Germany, and the United States accounting for the largest share. These exports continued to grow, reaching approximately \$3.754 trillion in 2023. South Korea's high-tech exports in 1988 was 8.91 billion USD gradually increased until they reached 201.27 Billion USD in 2023, Germany's high-tech exports in 1988 was 33.6 billion USD continued to increase until they reached 256 billion USD in 2023, the United States' high -tech exports in 988 was 77 billion USD continued to increase until they reached 209 billion USD, The figure 1 shows the trend of development high-tech exports in South Korea, Germany, and the United States.

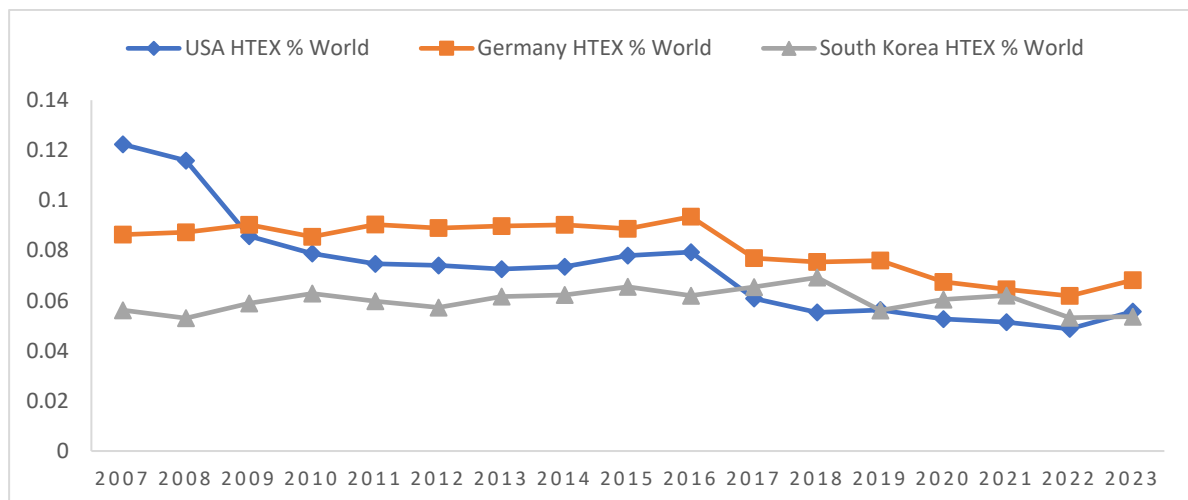
Figure 1. South Korea, Germany and United States High-Technology Exports trend (1988-2023) In Billion USD



Source: World Bank, OCED

Regarding the share of South Korea, Germany, and the United States high technology exports in globally. In 2007 the South Korea share was 6%, this decline to 5% in 2023. In 2007 Germany share was 9%, this decline to 7% in 2023. In 2007 the United States share was 12% sharply dropped to 6% in 2023. This decline in share for these countries is due to the fact that many countries have achieved significant growth in high-tech exports, such as China, whose exports peaked in 2021, recording \$936.39 billion, and its share of the global market for high-tech exports was 28.5%. Figure 2 show the South Korea, Germany and USA High-Technology Exports % World.

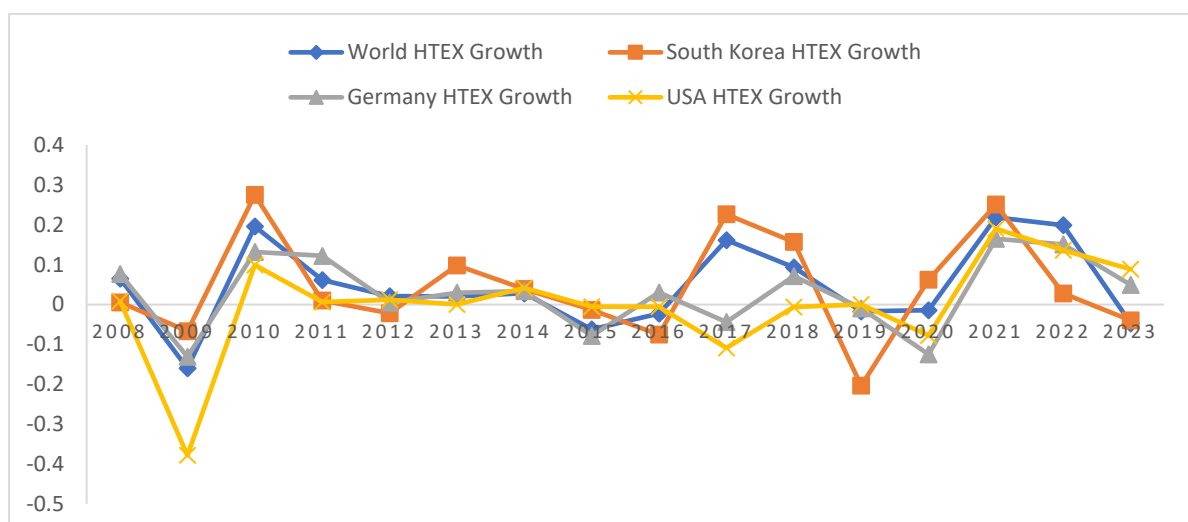
Figure 2. South Korea, Germany and USA High-Technology Exports % World



Source: World Bank

The worldwide growth rate of high technology exports in 2008 was 6%, In 2023 declined by 5%. The growth rate of high technology exports in 2008 was 1%, declined by 2023 4% in South Korea. In Germany the growth rate of high technology exports in 2008 was 1%, declined by 2023 4% in South Korea. In Germany the growth rate of high technology exports in 2008 was 1%, declined to 5% in 2023. Interestingly, in the United States the growth rate of high technology exports in 2008 was 1%, boosted to 9% in 2023. Figure 3 illustrates the growth trend in high-tech exports in the three countries compared to the global growth.

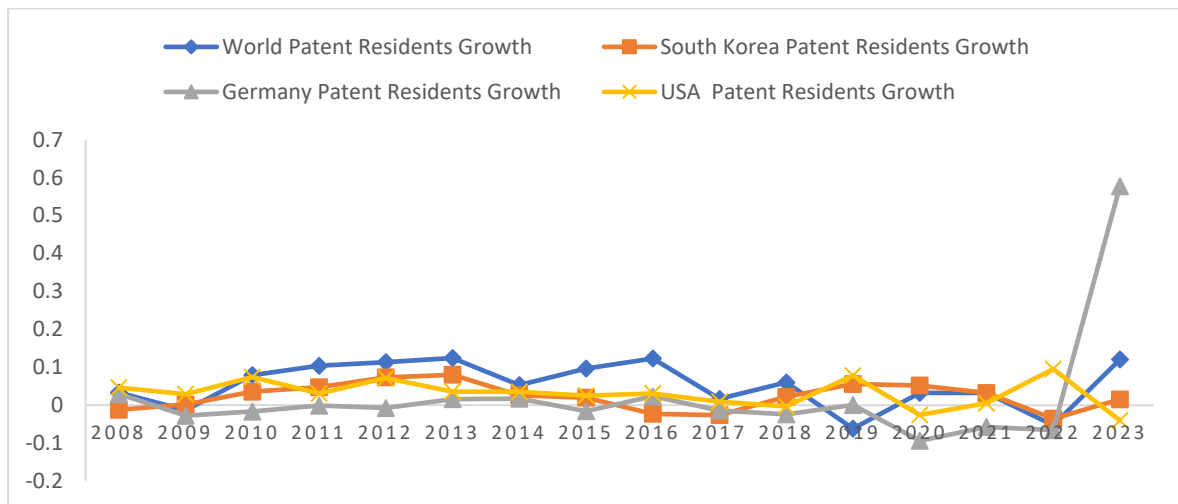
Figure 3. World, South Korea, Germany and United States High-Technology Exports trend growth (2008-2023)



Source: World Bank

Global patent growth in 2008 was approximately 3%, and in 2023 it reached 12%. Regarding patent growth in South Korea in 2008 declined by 1.2%, by the end of 2023 recorded growth reached to 1.5%. in Germany the patent growth was 3%, remarkably recorded 57% in 2023. Finally, in the United States the patent growth was 5 % in 2008, and by 2023 declined to 5%. Figure 4 show the Patents resident trend growth in the World, South Korea, Germany and USA during (2008-2023).

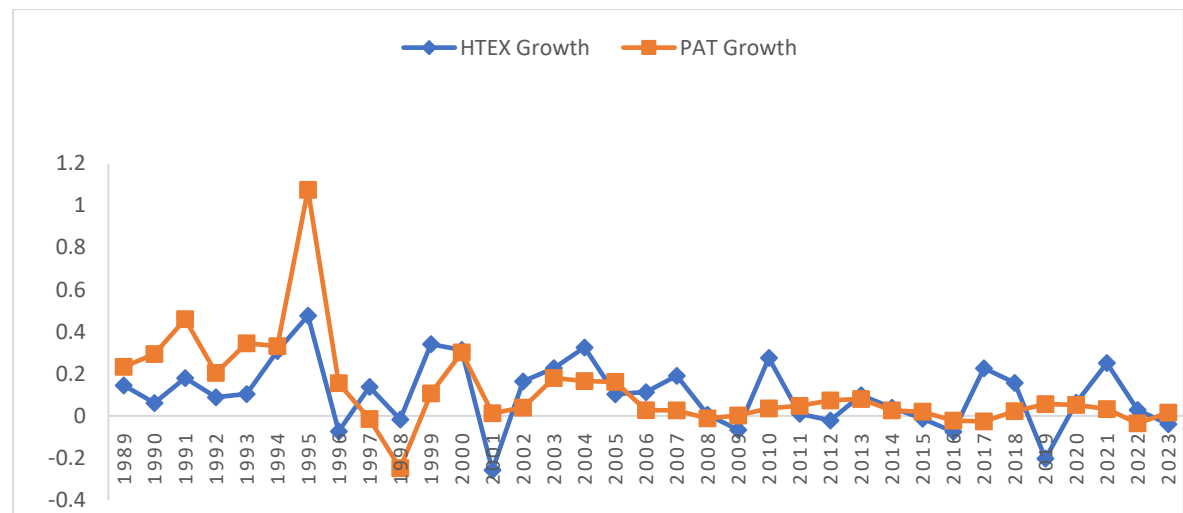
Figure 4. Patents resident trend growth in the World, South Korea, Germany and USA (2008-2023)



Source: World Bank

South Korea experienced significant growth in patents in the early 1990s, with growth peaking in 1989 at approximately 23%. In 1995, there was a meteoric growth reaching approximately 107%. After that, the growth rate continued to fluctuate and by 2023 reached 2%. Where the growth in high-tech exports recorded 14% in 1989. In 1995 there was a significant growth reaching approximately 47%. By the end of 2023 declined to 4%. The average growth in patents and high-tech exports was 12% and 10%, respectively. Figure 5 shows the growth in patents and Korean high-tech industries during the period 1989-2023.

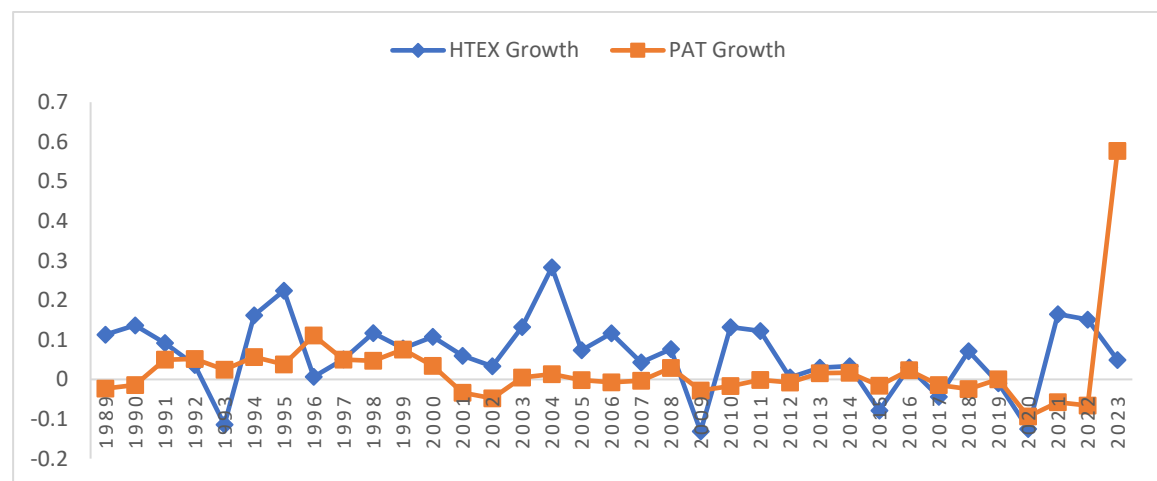
Figure 5. Growth of South Korea patents of resident and High-Technology Exports (1989-2023)



Source: World Bank, OCED

According to Figure 6 the growth of patents in Germany in 1989 declined 2%, continued to up and down until 2022, in 2023 the growth rate of patents grew significantly and recorded 57%. On the other side, the growth in high-tech exports during the period 1989-2023 was 11% in 1989 and 5% in 2023, with an average growth of 2% for patents and 6% for high-tech exports. Figure 6 shows the growth rate of German patents and high-tech exports during the period 1989-2023.

Figure 6. Growth of Germany patents of resident and High-Technology Exports (1989-2023)

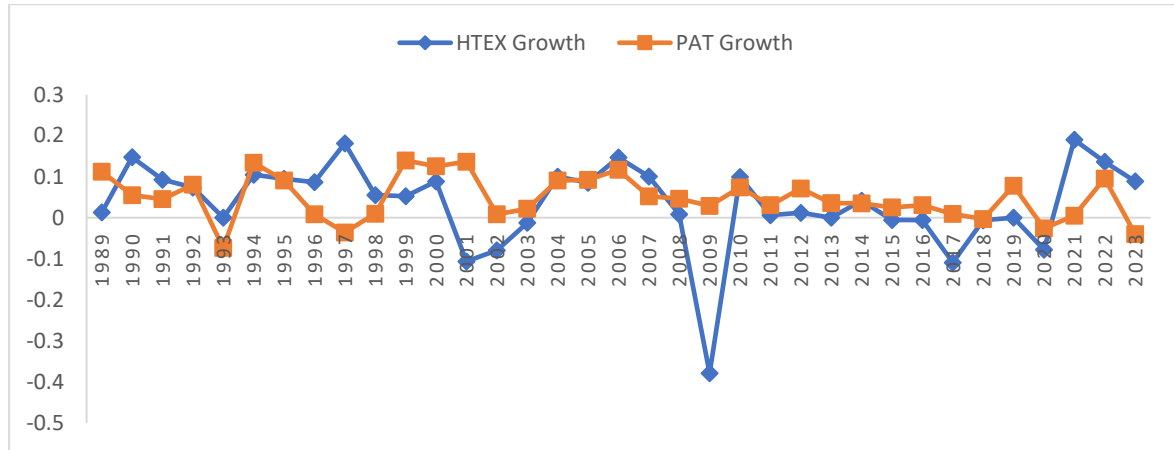


Source: World Bank, OCED

Finally, the growth of patents in the United States in 1989 was 11%, continued to up and down recorded decline by 4% in 2023. The United States is making great efforts to increase its high-tech exports. In 1989, the growth rate of high technology exports was 1.3% continued to fluctuate between high and low until 2009 which recorded sharp decline and then reached 37%. as a result of the global financial crisis, after that, it rose again and still fluctuate until 2023 which reached to 8%. The average growth in patents and high-tech exports during the

period 1989-2023 was 3% and 5%, respectively. Figure 7 shows the growth trend in patents and high-tech exports in the United States during the period 1989-2023.

Figure 7. Growth of United States patents of resident and High-Technology Exports (1989-2023)



Source: World Bank, OCED

In this study, the impact of innovation on high technology exports of the South Korea, Germany and United States for the period 1988-2023 were analyzed by using annual data presented.

Literature review

Exports of high-tech products and advancements in innovation have received significant focus in recent years. Numerous studies have particularly highlighted the globalization process of high-tech companies and their innovative assets (Crick & Jones, 2000; Kelly et al., 2021; Aghion et al., 2022). Tebaldi (2011) has shown innovation is one of determinants of high-tech exports. Braunerhjelm and Thulin (2008) have revealed that R&D expenditure is an important determinant of high-tech exports.

D'Angelo (2012) studied how innovation affects the export intensity of small and medium-sized high-technology firms in Italy, utilizing a dataset with 3,452 observations that included a wide range of variables, encompassing both survey data and financial statements, analyzed through Tobit regression models. The findings indicate that employees involved in R&D have a positive and significant effect on the export intensity of high-technology SMEs, while R&D spending does not have the same impact; collaborating with 'Universities' as external R&D partners positively influences the export intensity of these firms; additionally, 'Product innovations' and the revenue generated from innovative activities significantly and positively correlate with export intensity.

Alemu (2013) examined the impact of R&D investments and the number of researchers on high-tech exports for the 1994–2010 period of 11 East Asian countries. The analysis using the

panel GMM estimation method concludes that the R&D expenditures/GDP ratio and the rise in the number of R&D personnel increase high-tech exports. Sandu and Ciocanel (2014) investigated the relationship between medium and high-tech exports, and the main determinants of innovation. The data for 26 countries (all EU-27 countries, except for Luxembourg), along the 2006-2010 period have been extracted from the 2012 Innovation Union Scoreboard. The results confirm a causal relationship between the independent variables mentioned above and the EU high-tech exports level. Moreover, results also confirm a positive correlation between total R&D expenditure volume and the level of high-tech exports, with variability between countries. The influence of private R&D expenditure on high-tech exports is stronger than public R&D expenditure.

Ghanbari and Ahmadi (2016) inspected the effect of innovation on international trade. It examines the impact of R&D as a proxy of innovation on three medium high-tech industries exports in Iran, Japan, Korea and Australia using panel data method over a period from 2003 to 2012. Findings show that innovation has a positive and economically large effect on export performance of all industries. This suggests innovation is a central driver of trade. Bayraktutan and Bidirdi (2018) investigated the effect of the number of patents on high and medium-high-tech export (HTEX) performance in developed and developing countries, panel co-integration methods separately for DC and LDC with the annual data of 16 DC and 10 LDC for the 1996–2012 period were used. Estimation results show that PAT (Patents of residents) is one of the key determinants of HTEX in both groups of countries and PAT elasticity of HTEX in developing countries is higher than that of developed ones. However, while there is no short-run causality from PAT to HTEX, there is short-run causality from GFC and FDI to HTEX.

Chaloti et al. (2020) studied the relationship between innovation, patents, and trade in Greece. The sample for the study includes the identities of exporting companies, their export characteristics, and their patent application activity from 2005 to 2007. The findings indicate that patents have a positive effect on export volume, and that innovative firms tend to export more than their non-innovative competitors, particularly in more remote markets. Panda and Sharma (2022) utilizing a meta-regression analysis, examines the impact of innovation on export performances. a meta-analysis from 27 empirical studies that contain 249 estimates undertaken during 1996–2019 used. Study findings show that developed countries' domestic innovation enhance their exports; however, for developing countries, innovation does not contribute to their exports. Tandrayen-Ragoobur (2022) investigates the relationship between innovation and export behaviour across manufacturing and services firms in Africa. Using data from 45 African countries, from 2006 to 2020, the multinomial probit and two-stage least squares models are estimated. There is support for the learning by exporting and the self-selection hypotheses for African firms. The findings reveal the need to improve the business environment across African economies to foster greater exports and innovation.

Recently, Zaman and Tanewski (2023) examined the “learning to export” and “learning by exporting” hypotheses in SMEs and large firms in Australia. Financial data are derived from the Australian Tax Office's (ATO), Business Income Tax (BIT), between 2001-2002, and 2018-2019. Using instrumental variable (IV) regressions and path analyses, the empirical

assessment provides evidence that R&D and innovation should be regarded as two separate constructs. Results also revealed that there is a significant mediating effects between R&D and Export via Innovation and between Export and R&D via Innovation only in the large company cohort. SMEs do not show evidence of simultaneity among R&D, innovation, and exporting nor do the results provide support for the “learning by doing” hypothesis in SMEs. Moreover, Zapata et al. (2023) investigated the factors influencing high-tech exports, presenting new findings from a study of 35 OECD countries over a period of 15 years (2004 to 2018). They employed panel data estimation methods, the results suggest that research and development, inward foreign direct investment relative to GDP, gross fixed capital formation, and membership in the EU are key determinants of technology-intensive exports.

Model Specification Methodology, and Data

Model Specification

The study examines the impact of innovation on high -technology exports for South Korea, Germany, and united states. The variables analyzed in the study were chosen based on existing literature and aligned with economic theory. Thus, Following (Sandu and Ciocanel, 2014; Bayraktutan and Bırdı, 2018; Vlčková and Stuchlíková, 2021; Chalioti et al., 2020; Gocer, (2013; Bottega and Romero, 2021). The study model specified and presented in Eq. (1).

$$HEX = F(PAT, FDI, GFCF, RD) \quad (1)$$

Where *HEX* represents the high technology exports, *PAT* residents patent a proxy of innovation, Grilliches (1990), Greenhalgh et al. (1994), and Madsen (2008) contend that patents serve as the most reliable metric for assessing technology. Grilliches (1990, p. 1661) states that patents “are inherently connected to creativity and are founded on what seems to be a stable and objective standard.” Patents can be quantified without inaccuracies and reflect the outcomes of both formal and informal research endeavors (Madsen, 2008). The existing literature also highlights a significant correlation between patent counts and R&D spending in a cross-sectional context (Grilliches, 1990; Greenhalgh et al., 1994; Madsen, 2008). This indicates that patents may effectively represent disparities in innovative activities among firms and/or nations. Additionally, Grilliches (1990) notes that although the tendency to patent differs across industries, the correlation between patents and R&D is nearly proportional. Most notably, patent data is generally more accessible than R&D data. Therefore, even though they are not perfect indicators of innovation, Grilliches (1990, p. 1700) remarked that “patent statistics continue to be a singular resource for examining the dynamics of technical advancement.” *FDI* foreign direct investment, *GFCF* gross fixed capital formation, and *RD* research and development expenditure % of GDP.

By applying the natural logarithm to both sides of equation (2), estimation function become as follows:

$$\ln HEX = C + \beta \ln PAT + \alpha \ln FDI + \delta \ln GFCF + \gamma \ln RD + e \quad (2)$$

Where *ln* denotes natural logarithm, *C* represents a constant parameter, *e* is the error term, *β, α, δ, γ*, denote respectively constant elasticity coefficients signs are expected to be positive.

Methodology Estimation

This research utilizes the ARDL bounds testing method for cointegration introduced by Pesaran, Shin, and Smith (2001) to analyze the empirical connections between the study variables. The ARDL model provides reliable outcomes, especially when dealing with small sample sizes.

$$\Delta HEX = C + \eta LHEX_{t-1} + \beta LPAT_{t-1} + \alpha LFDI_{t-1} + \delta LGFCF_{t-1} + \gamma LRD_{t-1} + \sum_{i=1}^p \eta_2 LHEX_{t-i} + \sum_{i=0}^p \beta_2 LPAT_{t-i} + \sum_{i=0}^p \alpha_2 LFDI_{t-i} + \sum_{i=0}^p \delta_2 LGFCF_{t-i} + \sum_{i=0}^p \gamma_2 LRD_{t-i} + \varepsilon_t \quad (3)$$

In this context, Δ denotes the first difference operator; C represents an intercept, ε_t error term, the long-run coefficients are labeled as $\eta, \beta, \alpha, \delta, \gamma$, whereas $\eta_2, \beta_2, \alpha_2, \delta_2, \gamma_2$ indicate the short-run coefficients that form the underlying ARDL model.

There are two steps involved in estimating the given model using the ARDL approach. ARDL Bounds testing begins with estimating the Equation (3) using the ordinary least square approach (optimal lags included). Subsequently, an F-test is conducted to assess the collective significance of the coefficients of the lagged levels of the variables being analyzed in the model. The F-test is used to determine if the variables of interest in Equation (3) have long-run cointegration interrelationships.

Two sets of critical values are created during the F-test for joint significance; these are known as the upper-bound critical values for the $I(1)$ series and the lower-bound critical values for the $I(0)$ series (Pesaran and Smith 1998). After that, if the computed F-statistic lies outside of the critical value bounds, a definitive conclusion about cointegrating relationships can be drawn by comparing the computed F-test statistic to the critical value bounds published by Pesaran, Shin, and Smith (2001). This procedure is the same as using the F-test statistic to assess the alternative hypothesis (H_1) of cointegration versus the null hypothesis (H_0) of no-level cointegration connection. Consequently,

$$H_0 : \eta = \beta = \alpha = \delta = \gamma = 0 \text{ is against } H_1 : \eta \neq \beta \neq \alpha \neq \delta \neq \gamma \neq 0$$

To test the null hypothesis (H_0) for cointegration against the alternative, if the calculated value of the F-statistic higher than the upper bound of critical values. The H_0 cannot be rejected. If the F-statistic is less than the lower critical value bounds, we accept alternative hypothesis H_1 option. However, conclusive inference is not possible when the calculated F-statistic falls between the higher and lower value ranges. After the cointegration relationship has been established, it is necessary to estimate the long-run coefficients of Equation (3). Subsequently, the short-run dynamics can be derived through the error-correction model (ECM) presented in Equation (4), which is outlined as follows:

$$\Delta HEX = C + \sum_{i=1}^p \eta_2 LHEX_{t-i} + \sum_{i=0}^p \beta_2 LPAT_{t-i} + \sum_{i=0}^p \alpha_2 LFDI_{t-i} + \sum_{i=0}^p \delta_2 LGFCF_{t-i} + \sum_{i=0}^p \gamma_2 LRD_{t-i} + \mu ECM_{t-i} + \varepsilon_t \quad (4)$$

Data

This study examines the impact of innovation on high-tech exports for South Korea, Germany and united states. Analysis data obtained from 1988 to 2023. Sources of data World Bank Database, OECD, WIPO, World Development Indicators, Ministry of Science and Technology (Korea), Science and Technology Annual 1993 (in Korean),

Descriptive statistics Table 1. are utilized to present information on a selection of variables. The findings indicated that the mean values for all variables fall within the anticipated range, confirming the absence of extreme values in the dataset. Despite this, the calculated standard deviation for the analyzed parameters suggests a sufficient degree of volatility in the data. Furthermore, the data for all the parameters used shows negative skewness, with none of the skewness values exceeding the specified limits of +1 and -1. For all considerations, each parameter analyzed exhibits a normal distribution, as demonstrated by the Jarque-Bera statistic and its corresponding probability. Consequently, researchers were able to leverage the provided data for further analyses, including variable estimation and empirical investigations.

Table 1. Descriptive Statistics

	LOG(HEX)	LOG(RD)	LOG(PAT)	LOG(GFCF)	LOG(FDI)
South Korea					
Mean	4.138431	1.058356	11.23353	5.553434	-0.290923
Median	4.478587	0.962899	11.72659	5.663411	-0.231505
Maximum	5.345445	1.650580	12.13482	6.355252	0.768245
Minimum	2.187091	0.609766	8.647519	4.113227	-1.551351
Std. Dev.	0.996828	0.346393	1.000284	0.594409	0.577241
Skewness	-0.567836	0.317683	-1.301461	-0.508610	-0.310350
Kurtosis	1.980231	1.564376	3.553547	2.382772	2.621322
Jarque-Bera	3.494522	3.697060	10.62243	2.123559	0.792996
Probability	0.174251	0.157468	0.004936	0.345840	0.672672
Germany					
Mean	4.736637	0.961402	10.68393	6.400882	0.833185
Median	5.026255	0.958413	10.75825	6.397958	0.969383
Maximum	5.545177	1.202972	10.97945	6.880396	2.610697
Minimum	3.514526	0.741937	10.33280	5.773994	-1.257033
Std. Dev.	0.643100	0.131880	0.162826	0.282365	0.679787
Skewness	-0.485901	0.032874	-0.878825	-0.286808	-0.419693

Kurtosis	1.728950	1.898542	2.725868	2.379735	4.599767
Jarque-Bera	3.839950	1.826299	4.746720	1.070645	4.895736
Probability	0.146611	0.401258	0.093167	0.585481	0.086478
United States					
Mean	5.035022	0.994603	12.07643	10.16744	0.346510
Median	5.114991	0.962219	12.17164	10.21817	0.370553
Maximum	5.493061	1.243512	12.79559	10.99030	1.225474
Minimum	4.343805	0.832909	11.13669	9.373209	-0.766032
Std. Dev.	0.284027	0.106726	0.538413	0.465798	0.475873
Skewness	-0.905710	1.117529	-0.233069	-0.179563	-0.291184
Kurtosis	3.332656	3.438651	1.568049	2.031692	2.708532
Jarque-Bera	5.087851	7.781842	3.401652	1.599889	0.636161
Probability	0.078557	0.020427	0.182533	0.449354	0.727544

Empirical results

In Table 2, the findings of the optimal lag selection are displayed. Identifying the best lag in the ARDL model aims to address the issue of autocorrelation within the model system by treating the lag in endogenous variables as an exogenous variable. The optimal lag determination is based on the likelihood ratio (LR), final prediction error (FPE), AIC, Schwarz information criterion (SIC), and Hannan–Quin criterion (HQ) values. As indicated in Table 2, the chosen lag is lag 2 , 3, 4 regarding to South Korea, Germany, United States respectively. Selecting lag 2, 3, 4 as the optimal lag implies that all variables not only influence each other in the same period but also in the preceding two periods, three periods, four periods in south Korea Germany and USA.

Table 2 lag selection

South Korea						
Lag	LogL	LR	FPE	AIC	SC	HQ
0	-4.747762	NA	1.22e-06	0.573398	0.797863	0.649947
1	158.8574	269.4673	3.58e-10	-7.579844	-6.233056*	-7.120551*
2	189.4128	41.33978*	2.86e-10*	-7.906638*	-5.437525	-7.064600
Germany						
0	44.27030	NA	6.37e-08	-2.380018	-2.153274	-2.303726
1	197.1317	250.1369*	2.80e-11	-10.12919	-8.768733*	-9.671441*
2	223.1759	34.72565	2.94e-11	-10.19248	-7.698302	-9.353266
3	254.3733	32.14270	2.76e-11*	-10.56808*	-6.940180	-9.347400
United States						
0	64.58891	NA	1.66e-08	-3.724307	-3.495286	-3.648393
1	234.1302	275.5046*	2.03e-12*	-12.75814	-11.38401*	-12.30265*
2	256.8097	29.76681	2.65e-12	-12.61311	-10.09387	-11.77805
3	280.1239	23.31418	4.17e-12	-12.50774	-8.843402	-11.29312
4	320.3238	27.63748	3.61e-12	-13.45774*	-8.648294	-11.86354

Before engaging in cointegration, it is essential to perform unit root tests to assess the stationarity characteristics of the parameters and then conduct descriptive statistics to ensure normality. This step is vital as it aids in selecting an appropriate test for the subsequent phase of the study and identifies the type of stationarity of the parameters being analyzed. Two-unit root testing methods were implemented in this study. As shown in Table 3, all parameters evaluated displayed stability at level $I(0)$ or after the first difference $I(1)$. This indicates that cointegration and the ARDL estimator can be utilized with the data.

Table 3 The results of unit root tests

Variable	Augmented Dickey-Fuller		Phillips-Perron	
	At level	First difference	At level	First difference
South Korea				
LOG(HEX)	-3.094990**	-5.800460***	-6.041087***	-6.404840***
LOG(RD)	0.293156	-4.260023***	0.294879	-4.175078***
LOG(GFCF)	-2.397531	-5.319329***	-2.463143	-5.386850***
LOG(FDI)	-2.766908*	-6.078349***	-2.286636	-7.990698***
LOG(PAT)	-8.495340***	-2.246927	-15.33504***	-3.408929**
Germany				
LOG(HEX)	-1.779234	-5.470229***	-1.915708	-5.470229***
LOG(RD)	0.564516	-3.903786***	-0.226894	-2.967431**
LOG(GFCF)	-1.599231	-5.370647***	-1.598772	-5.370647***
LOG(FDI)	-3.915639***	-8.219739***	-3.879970***	-9.401636***
LOG(PAT)	-1.727242	-2.738657*	-1.447831	-2.084684
United States				
LOG(HTEX)	-2.366835	-5.093943***	-2.388365	-5.097152***
LOG(RD)	-0.261542	-4.359353***	0.239443	-4.247688***
LOG(GFCF)	-0.281863	-3.943233***	-0.241444	-2.909200*
LOG(FDI)	-3.106302**	-7.248305***	-3.159991**	-9.372738***
LOG(PAT)	-2.067688	-5.478404***	-1.783604	-5.456986***

*, ** and ***, 1%, 5% and 10%

The dataset's stationarity can be assessed based on the results from the unit root tests. An ARDL bounds test was conducted to evaluate whether a cointegration relationship exists among the parameters utilized. The results of the cointegration analysis are presented in Table 4. The computed F-statistic for cointegration (9.32), (8.67), (4.99) regarding to South Korea, Germany, and United states respectively, exceeds the maximum permissible limit. This study identifies a cointegration relationship among the variables.

Table 4. ARDL Bounds Test Results

Null hypothesis: No degree of relationship

			South Korea	Germany	United states	Result
Signif.	I(0)	I(1)				
10%	2.2	3.09	F = (9.32) K 4	F = (8.678) K 4	F = (4.991) K 4	Cointegrated ***
5%	2.56	3.49				
2.5%	2.88	3.87				
1%	3.29	4.37				

*, ** and ***, 1%, 5% and 10%

The results of the long- and short-term tests showed that Korean high-tech exports had a positive impact on all variables. In the long-term, a 1% increase in patents contributes to a 43% increase in high-tech exports, while in the short-term, they increase by 22%. Foreign investment contributes to a 13% increase in exports with a 1% increase in the long term, and 8% in the short term. Fixed capital accumulation contributes 70% to high-tech exports with a 1% increase, meaning that a large portion of this accumulation finds its way into technology industries. In the German case, patents have a significant impact on high-tech exports, as a 1% increase in patents contributes to a 3.06% increase in exports in the long run and a 43% increase in the short run. Capital formation also has a positive impact on high-tech exports, as a 1% increase in patents contributes to a 1.27% increase in exports in the long run and a 52% increase in the short run. Spending on scientific research has a negative impact on high-tech exports, as a 1% increase in spending leads to a decrease in high-tech exports in the short run. This is because this spending has not led to an increase in labor productivity in high-tech industries (Naudé and Nagle, 2017). Finally, the results of the test in the US case showed that capital accumulation in the United States contributes approximately 1.28% to high-tech exports with a 1% increase in the long run. In the short run, high-tech exports increase by 44%, 2.61%, 9%, and 1.7% when patents, fixed capital accumulation, and foreign investment increase. Spending on research and development by 1% respectively.

Table 5. long and short run results

Co.	Variable	Long run		Short run	
		coefficients	Prob.	Coefficients	Prob.
South Korea	LOG(PAT)	0.431980	0.0086	0.223170	0.0706
	LOG(FDI)	0.139950	0.0597	0.080295	0.0446
	LOG(RD)	0.198317	0.6758	0.113783	0.6901
	LOG(GFCF)	0.743535	0.1146	0.705064	0.0000
	C	-4.897909	0.0000		
	ECM			-0.573741	0.000
Germany	LOG(PAT)	3.069782	0.0000	0.429744	0.0021
	LOG(GFCF)	1.269403	0.0003	0.522016	0.0043
	LOG(FDI)	-0.119050	0.2521	-0.011910	0.4648
	LOG(RD)	-0.266118	0.7535	-1.170340	0.0045
	c	-35.70253	0.0000		
	ECM			-0.411230	0.000
United States	LOG(PAT)	-0.651520	0.0884	0.441307	0.0312
	LOG(GFCF)	1.283862	0.0232	2.616597	0.0000
	LOG(FDI)	-0.003595	0.9888	0.095309	0.0017
	LOG(RD)	0.188040	0.9114	1.732293	0.0090
	c	-0.883342	0.7237		
	ECM			-0.347707	0.000

The ECM value mirrors the speed at which the system moves from a temporary balance to a state of permanent stability. Both the coefficient and the derived ECM are negative at the 1% significance level. According to the ECM values in South Korea, Germany, and united state models, short-term deviations from the long-term equilibrium path are generally adjusted by an average of 57.37 %, 41.12%, 34.77 % each year respectively. The significantly negative ECM coefficient indicates that any long-term disparities among the model variables will adjust or align with the long-term equilibrium.

This study employed various diagnostic tests to verify the reliability of the ARDL findings. The Breusch-Godfrey Langrage Multiplier (LM) test for autocorrelation is displayed in Table 6. The findings indicate that there is no serial correlation present. The Breusch-Pagan-Godfrey test for heteroskedasticity demonstrated that the data do not show signs of heteroskedasticity. To

assess the normality of the series, the Jarque-Bera Normality test was conducted. The statistics from the Jarque-Bera test and the corresponding p-value indicated that the residuals follow a normal distribution.

Table 6. Results of Diagnostic Tests

Diagnostic tests	Soth Korea		Germany		United states		Decision
	Coef.	Prob.	Coef.	Prob.	Coef.	Prob.	
Jarque-Bera test	0.147	0.929	2.267	0.321	3.77	0.152	Residuals are normally distributed
Breusch-Godfrey Serial Correlation LM Test:	0.740	0.489	1.951	0.158	3.333	0.082	No serial correlation exists
Breusch-Pagan- Godfrey	0.297	0.969	1.356	0.2638	0.801	0.680	No heteroscedasticity exists
Ramsey Reset test	0.015	0.902	1.648	0.214	1.150	0.309	The model is properly specified

Conclusion

Technological progress influences global competition; nations that develop technology and utilize it effectively within their economic activities tend to have stronger economies. When examining the commodity composition of international trade, it becomes evident that the proportion of technology-driven products or production processes in overall world trade is steadily increasing; the rise in high-value-added products and the monopolistic advantages gained from complex technological goods or processes make this trend more appealing than ever. This study analyzed the influence of patent numbers, serving as an indicator of innovation, on exports from the high and medium-high-tech manufacturing sectors in South Korea, Germany, and the United States over annual periods. Additionally, variables such as Research and Development as a percentage of GDP, Gross Fixed Capital Formation, and Foreign Direct Investment inflows as a percentage of GDP were utilized to elucidate high-tech export levels. The stationarity characteristics of the variables were assessed using panel two-unit root tests, and the existence of a long-term relationship among the variables was examined through cointegration tests. Given that the results from the cointegration tests indicate a long-run equilibrium between the pertinent variables, cointegration coefficients were further analyzed using the ARDL Bounds Test.

The result of long run show that the patent has positive impact on South Korea and Germany high technology exports, in addition, in short run the patent has positive impact on South Korea Germany, and united states high technology exports, thus the patent is the main important determinants of high technology exports. Additionally, the error correction coefficient (ECM) was determined to be both negative and significant, indicating that the error correction mechanism is functioning and that short-term imbalances are rectified over the long term.

Based on the above findings, the study recommends that increasing high-tech exports requires increasing patents. Countries that wish to boost their exports should work to promote and encourage innovation by motivating individuals and companies to present patents in the high-tech sector.

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