Erasmus University Rotterdam

Erasmus School of Economics

Bachelor thesis, international economics.

R&D investment intensity and high technology exports

A case study on South Korea

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02-08-2024

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Abstract

Global economic competition around precuring a leading position in important high technology manufacturing sectors has become increasingly heated. Governments and national industries are looking for solutions to maintain and grow their market share on the international stage. This paper studies the effect of changes in the level of gross domestic research and development expenditure on the absolute value of high technology exports in Korea between 1991 and 2022. Korea is chosen as the focus point for this research as the development of its high technology industries is a general success story. Focusing on one economy to determine the relationship between R&D investment intensity and the absolute value of high technology exports is a novel approach when compared to existing literature. The objective of this approach is to analyze to what extent the success of Korea's high technology manufacturing sectors can be attributed to their high emphasis on R&D as a means of driving economic growth. To find an estimate for the effect of R&D investment intensity on the absolute value of high technology exports this paper employs a multiple linear regression model based on data from the OECD databank. This approach uses yearly data on Korea between 1991 and 2021 and employs control variables to account for other determinants of high technology trade. The results of the multiple linear regression model find a positive statistically significant association between R&D investment intensity and high technology exports in Korea between 1991 and 2021. This implies that Korea's R&D investment have increased the absolute value of its high technology exports. In addition to a multiple linear approach this paper attempts to make a stronger claim for a causal link between R&D investment intensity and high technology exports by analyzing the policy: "The Long-term Vision for S&T Development Towards 2025" using a difference-in-difference approach. The results from the difference-in-difference models find no statistically significant effect of the policy introduction on high technology exports. However, due to potential problems with the robustness of the results from the difference-in-difference models the effects of the policy introduction remain ambiguous. This paper concludes that R&D investment intensity has had a positive significant association with high technology exports in Korea between 1991 and 2022. Further research is necessary to define the magnitude of this association and to further substantiate a causal relationship.

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I. Introduction

Leading companies operating in high technology sectors are the flagships of most economies. They provide high levels of sustainable returns and high-quality job opportunities. Additionally, they produce goods that are essential for waging war, good health, communication, transportation, food security and many more aspects from our way of life. To all major economic powers these sectors are important for their economic independence as well as their economic growth. For developing economies looking to improve the wealth of its citizens these sectors provide an economic opportunity to increase the quality of employment. Because of the economic potential of these industries large public and private funds are allocated to the development of a competitive position in high technology sectors (European Investment Fund, 2023). The size of the funds at stake makes researching the determinants of growth in high technology manufacturing sectors an important and interesting topic.

These determinants of growth have been studied by looking at a large group of developed economies. Most studies use data from a large pool of countries to create a panel data analysis that estimates the effects of multiple determinants on the growth of high technology manufacturing sectors (Braunerjehlm & Tulin, 2008; Ferragina & Pastore, 2007; Zapata et al., 2023). This study takes the opposite approach by looking at one specific country over a longer period and focusing on one important determinant of growth. This research examines the relationship between gross public and private expenditure on R&D as a percentage of GDP and high technology exports in South Korea. Going forward, gross domestic spending on R&D as a percentage of GDP is defined as R&D investment intensity. South Korea, or Korea for short, is interesting to study in the context of this research because it has an unique position when it comes to high technology manufacturing and R&D. Korea sits among the top countries of high technology exporters boasting many large high technology manufacturers like Samsung, LG, Hyundai, Kia, POSCO and SK Group. These companies together with Korea's research institutions put heavy emphasis on innovation making Korea one of the leading innovators globally (Savrul & Incekara, 2015). To obtain this level of innovation Korea focusses heavily on R&D. Between 1990 and 2022 Korea's R&D investment intensity saw a massive increase growing from 1,72% in 1991 to the second highest in the world at 4,9% in 2022 (OECD, 2023a). This development of Korea's high technology sectors has played a significant role in Korea's economic development. Starting from 1990 Korea's high technology manufacturing sectors grew rapidly providing high quality job opportunities to millions of Koreans and thereby attributing to the rising quality of living in Korea as well as its economic growth (Harvie & Lee, 2003).

Existing literature on the determinants of growth in high technology manufacturing sectors has already determined that R&D investment intensity plays a significant role in stimulating growth in these sectors. However, there is still a gap in academic knowledge on the magnitude of the effect. Additionally, there is no empirical or theoretical research that specifically aims to analyze the effect that R&D investment intensity has had on the absolute value of high technology exports in Korea. Finally, there is a lack of papers that look at the long-term effects of R&D investment intensity. This paper attempts to add to the existing literature by providing a more in dept analysis of the effects of R&D investment intensity focusing on data from Korea. The objective of this paper is to determine whether the Korean strategy of focusing on R&D to improve international competitiveness on the high technology markets was successful at growing the absolute value of the country's high technology exports. The paper takes a novel approach by looking at the effects of R&D investment intensity over a longer period then most existing literature with the goal of making a more accurate estimate of the long-term effects of R&D investments.

To find the relationship between Korea's investment intensity and its high technology exports this study investigates the main research question: *what is the effect of R&D investment intensity on the absolute value of high technology exports in Korea between 1991 and 2022?* To answer this question the paper uses a multiple linear regression model based on yearly data between 1991 and 2021 controlling for other determinants of high technology exports such as: human capital, foreign direct investment, trade openness, quality of political institutions, wage convergence with other industrial economies and internal market size. Additionally, the model controls for macroeconomic trends like country GDP and growth of global market size. This study also looks at model specifications that include a three-year lagged variable for R&D investment intensity to account for any delayed effects of R&D investment and to rule out potential problems of reverse causality. Furthermore, this research employs a wide range of robustness checks to assess the validity of the results. This study first looks the variance inflator factor then it performs a Breusch–Pagan test followed by a Durbin-Whatson test and finally the Ramsey RESET test. Due to the complex nature of international competitiveness this study predicts the multiple linear regression model to face problems of omitted variable bias. To make a stronger argument for a causal relationship between R&D investment intensity and high technology exports this study uses a difference-in-difference method to analyze a quasi-natural experiment. "The Long-Term vision for S&T Development Towards 2025" is the first policy introduced by the Korean government with the goal of regulating the long-term development of science and technology in the country. This policy that was introduced in 1999 is the subject of the difference-in-difference analysis. The model is based on data from 1991 to 2022 and controls for other determinants of high technology exports like: human capital and foreign direct investment as well as underlying macroeconomic trends though the addition of GDP. The model is subjected to a Breusch–Pagan test to check for heteroskedasticity.

The main results from the multiple linear regression model indicate a statistically significant association between R&D investment intensity and the absolute value of high technology exports with a positive sign. Analyzing the results this study finds that an increase of 1% to the investment intensity increases high technology exports by approximately twenty billion. The models that include the three-year lagged variable for R&D investment intensity indicate no problems of reverse causality. The results from the difference-in-difference models find no statistically significant relationship between "The Long-term Vision for S&T Development Towards 2025" and high technology exports. Thus, indicating that there is no relationship between R&D investment intensity and high technology exports. However, due to problems in the model set up and with the robustness of the results this result cannot be interpreted.

This paper concludes that R&D investment intensity has a positive statistically significant association with the absolute value of high technology exports in Korea between 1991 and 2022. From the magnitude of this association, it follows that the level of R&D investment intensity has played a significant role in the development of Korea's internationally competitive position on the markets for high technology goods. From these conclusions it follows that Korea's strategy of focusing on a high level of gross domestic R&D investment is successful at growing a strong competitive position on the international markets for high technology manufactured goods. Other economies that are interested in developing their own high technology sectors could learn from this strategy. However, due to a lack of observations and problems with the robustness of the results in the multiple linear regression models as well as the difference-in-difference models make it difficult to fully substantiate these claims. Further research should try to resolve these issues to make a stronger claim for a causal effect of R&D investment intensity on the absolute value of high technology goods in Korea between 1991 and 2022.

This paper will start by giving an overview of the research topic and the theoretical arguments for an effect of R&D investment intensity on high technology exports. Following that is an analysis of the existing empirical literature on this topic. After this comes a summary of the data and other determinants of high technology trade. In the following section the model specifications and methodology are explained subsequently followed by the results and the limitations. Finaly, this paper ends with the conclusion, bibliography, and appendix.

II. Theoretical framework

2.1 Overview of the main variables of interest

This study focusses on the relation between public- and private R&D investment and its effects on the absolute value of high technology exports. According to the Frascati Manual written by the OECD (2002) R&D can be defined as the following: “Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.” (OECD, 2002, p. 30). This definition covers three different activities: basic research, applied research and experimental development. Basic research is the development of new knowledge without any prior application in view. Applied research encompasses all investigations with a particular aim of obtaining a certain knowledge. Lastly experimental development covers systematic research building on existing knowledge to further development in certain fields (OECD, 2002).

High technology goods can be defined as goods that have been developed with a high R&D intensity. According to the Standard International Trade Classification high technology products can be assigned to one of nine different product groups. These groups are aerospace, computers and office machines, electronics-telecommunications, pharmacy, scientific instruments, electrical machinery, chemistry, non-electrical machinery, and armament (Eurostat, n.d.).

2.2 History of Korean export-led growth

Korea’s prominent position in the international market for high technology sectors like the semiconductor- and the EV industry must be analyzed in the context of the country’s long-standing effort to foster economic growth through exports. In the second half of the 19th century Korea went from a developing agricultural economy to one of the four industrialized Asian tiger economies. A large part of this economic development was achieved through export focused manufacturing. In their research on the major factors behind the transformation of the Korean economy Harvie & Lee (2003) note the important role of the government in the transition that made Korea an export focused manufacturing economy. In the early stages of economic development, the government would provide investment capital using public funds and even set export targets for private firms that were tied to benefits like cheap loans or tax cuts. In this stage Korea’s economic growth can be explained by the catch-up effect. This is an empirically proven theory that states that developing economies, on average, have a higher and more volatile growth rate than already developed economies (Lin, 2003). Between 1960 and 1970 Korean manufacturing exports were driven by wage advantages that stemmed from poor economic development rather than from technological expertise. During this stage Korea was still dependent on foreign technology for its production capacity (Jung & Mah, 2013).

This started to change from the 1970s onwards. Between 1970 and 1980 Korea started a process of industrialization. This also led to the development of more endogenous technological capabilities. This was accomplished through government funded investments in import substituting industrialization and heavy industry. Another economic development that took place during this decade is the consolidation of economic power by the Korean chaebols. These chaebols are large economic conglomerates that are owned by a single family or a group of families. By the 1980s these families would control a large interest in all major economic sectors. This meant that the strategy of these chaebols would increasingly dictate the functioning of the Korean economy. Meanwhile during this same decade, the Korean government starts to take a less direct role in promoting exporting among the nation's private firms. The consolidated economic power and resources of the chaebols played a key role in the establishment of high technology sectors in Korea. Because of their large economic power, these chaebols were able to pay for the massive fixed cost that serve as entrance barriers to the market for high technology manufacturing like building manufacturing plants and setting up research and development facilities. Today these chaebols still own a mayor stake in technologically advanced producers like Samsung, LG, and Hyundai. Starting from the 1980s, rather than directly involving itself in company policy the government would now promote exports by liberalizing its economic restrictions and focusing on economic stabilization. During this decade, the government would enact economic policies that reduced inflation and price volatility, improved trade openness and liberalized financial markets. Importantly this allowed Foreign direct investment to increase massively during this period. Up until this point businesses where mostly financed through national capital sources and foreign loans. From this point forwards the government would stimulate export growth by providing favorable economic conditions to strategic sectors (Harvie & Lee, 2003). Among these strategic sectors where a lot of medium and small businesses in the technology manufacturing sector. These companies where and still are massive drivers of research and development.

Around 1990 is when the absolute value of exports that are driven by comparative advantages in the manufacturing of high technology goods start to pick up. This economic state continues until 1997 when Korea faced the Asian Financial Crisis. During this crisis, a lot of Korean national banks came into bad weather because of bad performing loans to the chaebols. The resulting crisis eventually required the IMF to intervene with a conditional loan. As part of the conditions, Korea was required to change its economic structure introducing tight monetary and fiscal policies improving labor market flexibility and further liberalizing its financial market (Vechsuruck, 2024). However the IMF crisis did not obstruct growth of high technology exports for very long. Between 1990 and 2004 the share of high technology manufacturing exports in total exports would continuously increase with growth in the absolute value of high technology exports outpacing growth in total export value (The World Bank, n.d.-h). Today, Korean high technology manufacturing exports are still largely subjected to the economic structure that originated from policies introduced in the aftermath of the IMF crisis (Vechsuruck, 2024).

Figure 1, Percentage growth in the absolute value of total exports and high technology export in Korea:

Source: (The World Bank, n.d.-g; Trading Economics, n.d.-a)

2.4 Empirical literature

The effect of R&D investment intensity on the absolute value of high technology exports has been investigated by a number of academic papers. The following section discusses the similarities and deviations in their results and research design to identify the grey areas in the literature. There are a number of studies that employ a multi-panel data model to research the determinants of high technology exports. These studies all use absolute levels of high technology exports as the dependent variable and include a plethora of independent variables to try to measure their effect. Zapata, et al. (2023) employing a dataset that includes 35 OECD countries between 2004 and 2018 find a significant positive relationship between R&D investment as a percentage of GDP and absolute value of high tech exports. Ferragina and Pastore (2007) in a sample of 82 developed and undeveloped countries between 1994 and 2003 find a similar positive effect for R&D investment on absolute value of high technology exports.

Braunerjehlm and Tulin (2008) also employ a panel dataset but rather then looking at absolute values of high technology exports they examine the effect of R&D investment on high technology exports as a percentage of total exports. Using data on 19 OECD countries between 1981-1999 finds that increasing R&D investment as a percentage of GDP by one percentage point leads to an increase in high technology exports as a percentage of total exports by 3%. In addition to these findings, Braunerjehlm and Tulin (2008) also discuss a potential explanation for empirical anomalies in the data. These anomalies are countries with high levels of R&D investment but low levels of high technology exports as a percentage of GDP or vice versa. They suggest that some countries specialize in medium-intensive technological production thereby causing a large part of a country's R&D investment to be absorbed by this industry. This causes a downwards bias in the effect of R&D investment on high technology exports because rather than boosting high tech exports these R&D investments are utilized to develop a larger medium-level manufacturing sector. These gains are not visible in the data.

Sandu and Ciocanel (2014) also investigate the effect of R&D investment intensity on high technology trade using the same dependent variable as Zapata, et al. (2023) and Ferragina and Pastore (2007). However, they employ a multiple linear regression in favor of a panel data approach to estimate the effect of R&D investment. Another novelty in their approach is the fact that they split the effect of public versus private R&D investment as a percentage of GDP when looking at their effects on high technology exports. Using data from all 25 EU member states between 2006 and 2010 they find that both public as well as private R&D investment has a positive effect on high technology exports. They do not manage to find a definitive conclusion as to which one has the higher magnitude. Sandu and Ciocanel (2014) also introduce five year and two year lagged R&D variables into the model proving a significant association between the lagged government R&D expenditure and the absolute value of high technology exports. Finally Sandu and Ciocanel (2014) also investigate some paradoxical empirical examples like Romania that boast relatively high levels of high technology export while having low levels of R&D investment and national technology capacity. They argue that these paradoxical cases are caused by the inability of databases to distinguish between high technology exports that stem from internal development or from the assembly of foreign imported high technological components. This causes countries with a large competitive advantage in the assembly of technological components like China to have an upwards bias in the effect of R&D investments on high technological exports.

2.5 Hypothesis

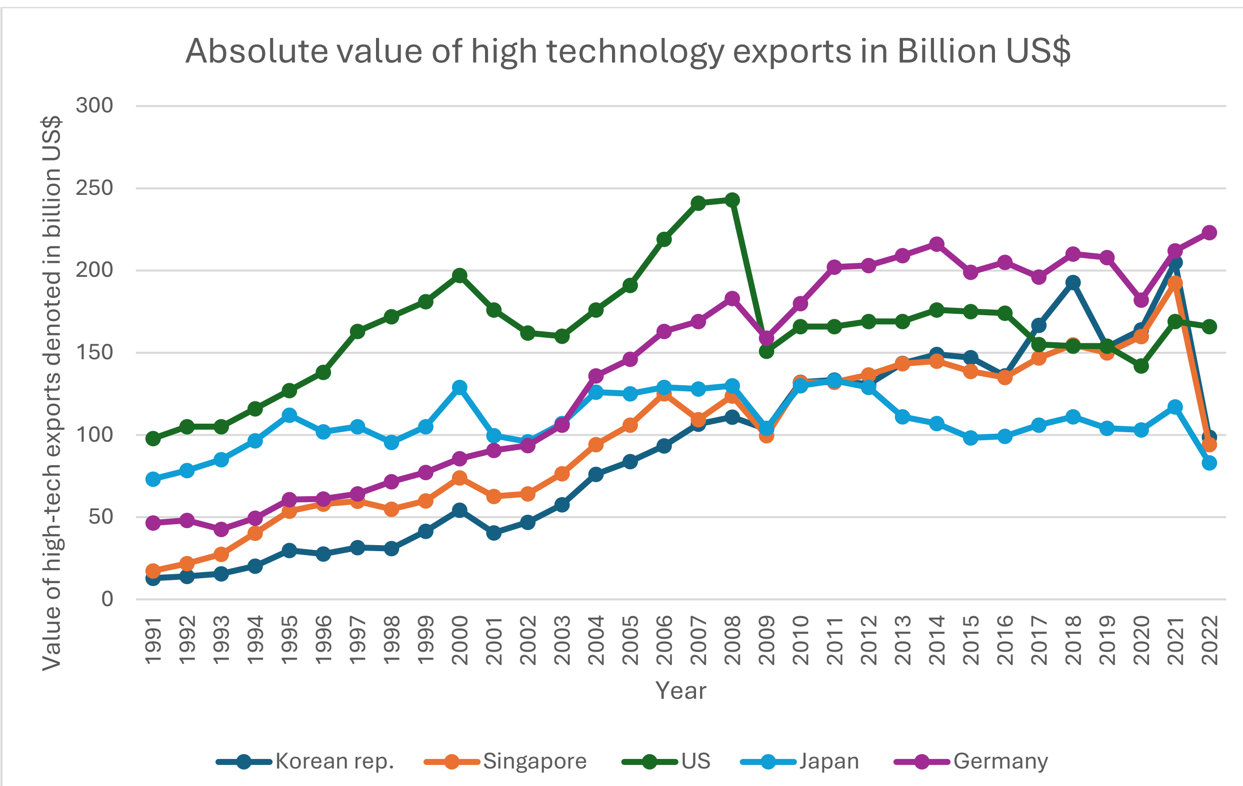
After analyzing the theoretical and empirical literature, a clear consensus arises on the effect of an increase in R&D investment intensity on the absolute value of high technology exports. Based on theoretical literature from Schumpeter (2021) and Porter (1998) combined with insights from empirical research on the determinants of high technology exports the effect of R&D investment intensity is expected to be positive. Based on these insights the hypothesis for this study is: *R&D investment intensity has had a positive effect on the absolute value of high technology exports in Korea between 1991 and 2022.*

III. Data

3.1 Primary endogenous and exogenous variables

This study tries to estimate the effect of changes in gross domestic expenditures on R&D as a percentage of GDP on the absolute value of high technology exports in Korea between 1991 and 2022. In previous studies by authors such as Seyoum (2004), Gökmen and Turen and Zapata et al. (2023) the absolute value of high technology exports have been used to determine a nations international competitiveness on international markets for high technology industries. This study uses data from Trading Economics that includes thirty-two observations for the years 1991 to 2022 as shown in figure 1. The data is expressed as the absolute value of high technology exports in billion US dollars. To visualize the development of the international market for high technology goods and show Korea's increasingly important position as an exporting country other regional and international market players have been added to the graph.

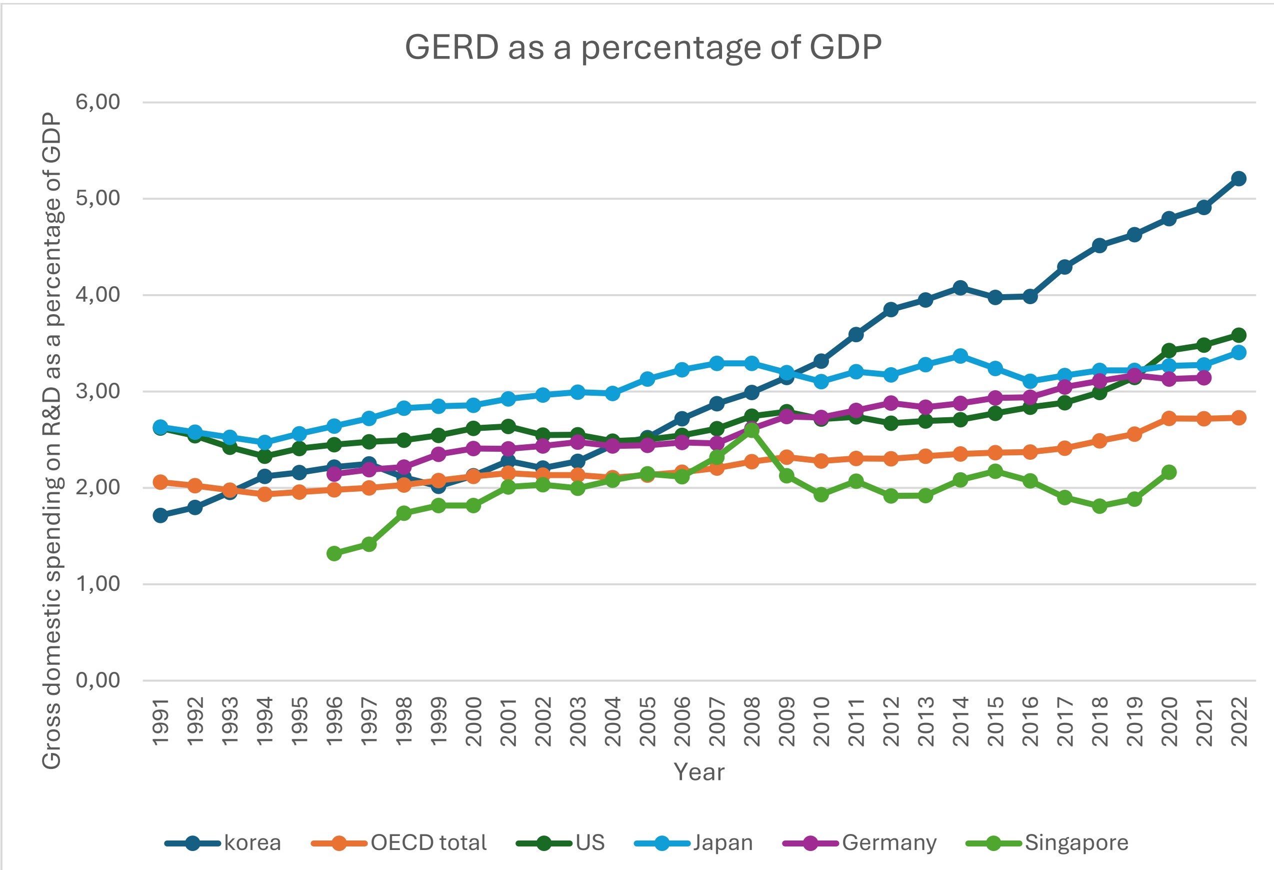
Figure 2, High technology exports:



Source: (Trading economics, n.d.-a)

Gross domestic expenditure on research and development (GERD) as a percentage of GDP functions as the primary exogenous variable of interest for this study. This variable has been used in previous literary studies like the research by Sandu and Ciocanel (2014) and Zapata et al. (2023) to investigate the effects of shifts in R&D investments on high technology exports. Data on this variable is extracted from the OECD databank and includes thirty-two observations from the year 1991 to 2022 (OECD, 2023a). The data is expressed in percentages and presented in figure 2 alongside observations from other regional and international players on the high technology export markets to put the observations from Korea into perspective.

Figure 3, GERD as percentage of GDP:



Source: (OECD, 2023a)

3.2 Other determinants of high technology exports

In addition to the level of R&D investment expenditures empirical research has identified a number of other determinants of a nation's high technology exports. To aid in the isolation of the effect of R&D investment intensity and to reduce the confounding effect of omitted variables these other determinants of high technology exports will be used for some of the multiple linear regression model specifications and to one of the difference-in-difference model specifications.

3.2.1 Foreign direct investment (FDI)

FDI is a term describing the foreign net inflow of either public- or private investment to acquire a lasting management interest in an enterprise consisting of at least 10% or more of the voting rights (Seyoum, 2004). Research by Tebaldi (2011), Seyoum (2004) and Gökmen & Turen (2013) have concluded that FDI plays an important role in determining a countries high technology exports. Seyoum (2004) explains this relationship through the important role of multinationals and technology transfers in high technology industries. Multinationals use FDI to acquire a stake in companies as they relocate parts of the production chain for their products. These large companies like Apple, Microsoft, and Boeing control most of the patents and knowledge that is necessary to produce their high technology goods. The production chains for these goods are widely scattered throughout the globe so that every step in the production is executed in the most optimal economic location. As multinationals expand or transfer parts of this supply chain, they use FDI to acquire an interest in their producers to maintain control over these phases of the production cycle. To ensure the quality of their product they provide some of their knowledge to these new manufacturers. This knowledge spillover is an important driver of innovation. For data on FDI this study will use World Bank data on FDI inflow in the Korean rep. between 1991 and 2022 (The World Bank, n.d.-a).

3.2.2 Human capital

Human capital determines the total economic and professional potential of a countries labor force. Lots of studies like the ones done by Tebaldi (2011) Seyoum (2004), Ferragina and Pastore (2007), Gökmen & Turen (2013) and Zapata et al. (2023) have all found a positive relation between a nations level of human capital and high technology manufacturing exports. Zapata et al. (2023) attribute this positive effect to the ability of a country's labor force to adapt to technological changes. As a country's human capital increases it is better able to incorporate high level technologies into its production. Seyoum (2004) and Gökmen & Turen (2013) attribute the positive effect of human capital on the absolute value of high technology exports to human capital aiding in domestic research and development efforts. In accordance with Tebaldi (2011) this study will use data by Our World in Data on the average years of schooling in the population of males and females twenty five years and older in the Korean rep between 1991 and 2022 as a proxy for human capital (Our World in Data, n.d.). Other studies like the one by Zapata et al. (2023) and Ferragina and Pastore (2007) use similar variables like the percentage of university graduates relative to the population group and the logarithm of secondary school enrolment ratio on net enrolment respectively as a proxy for human capital.

3.2.3 Trade openness

Research by Tebaldi (2011) and Gökmen & Turen (2013) has found that trade openness has a significant effect on a nations high technology exports. In accordance with the methods used by Gökmen & Turen (2013) this study uses data on trade freedom between 1995 and 2022 from the index of economic freedom by The Heritage Foundation (2023) to estimate trade openness in South Korea. In this dataset trade freedom denotes a score ranging from zero to a hundred that is determined by analyzing the trade-weighted average tariff rates and a qualitative evaluation of nontariff barriers (The Heritage Foundation, 2023). Here zero denotes low trade openness while a hundred denotes high trade openness.

3.2.4 Political institutions

The quality of a nation's political institutions is the last variable for which there is a broad academic consensus on its significant relationship with the absolute value of high technology exports. Studies done by Ferragina and Pastore (2007) and Tebaldi (2011) both find a significant effect of political institutions on high technology exports. However, as an important caveat to this conclusion Tebaldi (2011) finds that the effect of institutions becomes insignificant when adding human capital and FDI control variables to the model suggesting that institutions mostly affect high tech exports through human capital- and FDI levels. To determine the quality of Korea's political institutions this study will use the average value of the institutional quality indicators by The World Bank Data (The World Bank, n.d.-b).

3.2.5 Global demand

There are a number of variables that should influence high technology trade based on the theoretical literature but that have limited empirical evidence proving its effect. An increase in global demand and the size of the global market should theoretically increase high technology exports based on conclusions from the classical models on international trade (Leamer, 1995; Melitz et al., 2000). Research by Ferragina and Pastore (2007) assessed the possibility of world GDP having a pulling influence on high technology exports and found a significantly positive effect in a number of different model setups that included different selections of control variables. This study will include a similar control variable based on data from The World Bank Data on the worlds GDP level (The World Bank, n.d.-c).

3.2.6 Wage differentials

In 1991 Korea had a sizable wage advantage compared to other large manufacturing economies. Korea's government exploited this competitive advantage in the early stages of the development of Korea's manufacturing sector to induce growth through manufacturing exports. Over the years wages in Korea have converted to international wage levels reducing this competitive advantage (Jung & Mah, 2013). To control for wage competitiveness, this study includes a variable for the relative difference between Korean average wage levels and that of the competitive manufacturing economy of Japan. Data on wage levels is denoted in US dollars adjusted for purchasing power parity to 2022 and is sourced from an OECD database (OECD, 2023b). Japan has been selected as the comparative economy because of its similarities to Korea. Just like Korea, Japan has some advanced high technology industries with many famous companies that compete with Korean enterprises like Sony, Mitsubishi, Casio, and Canon to name a few. Additionally, Japan has a similar economic structure to Korea and is in the same geographical location (The World Bank, n.d.-i). All of these factors make Japan and Korea competitors on the international high technology export markets. Thus, wage convergence with Japan is a good proxy for Korea's diminishing competitive advantage resulting from low wage levels. Adding additional variables denoting wage convergence with other industrial economies like the US run into problems of multicollinearity. Therefore, wage convergence with Japan is used as a proxy for wage convergence with all global competitors.

3.2.7 Internal market size

The effect of internal market size on high technology exports has been a point of debate in the existing literature. Both Zapata et al. (2023) and Seyoum (2004) using different proxy variables find that the internal market size has a positive significant effect on high technology trade while Braunerjehlm and Tulin (2008) again using a different proxy find no effect. Because all studies are using a different proxy variable for internal market size, this could have affected the different conclusions. In accordance with the methodology of Zapata et al. (2023), this study will use population size as a proxy for internal market size using data from The World Bank (The World Bank, n.d.-d).

3.2.8 Gross domestic product

As a rule of thumb, economies that have a greater gross domestic product tend to have a higher value of total exports. A country that produces more or higher value products has more value to export. Thus, greater exports follow as a natural consequence of greater production. However, contrary to this there are cases of countries that have relatively high levels of exports and imports compared to the size of their economies. These anomalies can be explained by many factors. Maybe these countries are more focused on international trade, or they function as hubs through which imports flow to other countries (Akram, 2024). Most existing literature agrees that economic structural elements rather than aggregate macroeconomic factors are important for determining the level of the absolute value of high technology trade. To examen if GDP growth is a determinant of Korea's high technology exports this study includes Korea's GDP as a control variable. Data on Korea's GDP is from The World Bank (n.d.-e) and denoted in billion US$.

3.2.9 Omitted variables

Finally, some variables should theoretically influence high technology trade based on the Ricardian and Heckscher-Ohlin model but have been shown in existing empirical research not having a significant effect. These variables will not be added into the empirical model but are included this section to explain their omittance from the model. To start, relative differences in tax pressure could theoretically affect international competitiveness and high technology exports since they change comparative prices. However, empirical study done by Braunerjehlm and Tulin (2008) did not find a significant relation between implicit tax pressure and the absolute value of high technology exports. Secondly, research by Ferragina and Pastore (2007), Tebaldi (2011) and Seyoum (2004) finds no significant effect of changes in real exchange rates. Lastly, studies by Ferragina and Pastore (2007), Tebaldi (2011) and Braunerjehlm and Tulin (2008) find no significant relation between capital accumulation in an economy and high technology exports.

3.3 Missing and excluded observations

To get an accurate estimate for the effect of R&D investment intensity on high technology exports in Korea between 1991 and 2022 the observation from 2022 will be excluded from the data sample. This is because in 2022 high technology exports dropped a significant amount because of factors that are not incorporated into the statistical model revolving around the COVID-19 pandemic. Including this observation would skew the results leading to inaccurate estimates. As shown in figure 2, Korea's high technology exports dropped from 205 billion US dollars in 2021 to 99 billion in 2022. Though uncertain, it is likely that these low exports were caused by the pandemic. He and Wang (2022) through their study on the effects of the COVID-19 pandemic on the macroeconomic situation in Korea have found that the macroeconomic climate in Korea deteriorated as a result of the pandemic. They found that in 2021 output, consumption and investments decreased as a result of the pandemic. Since high technology manufacturing relies on long term planning and investments it is very plausible that Korea's high technology exports were subjected to a delayed negative effect of the Pandemic. Additionally in 2022 global demand was still recovering because of the international economic downturn caused by the responses to Covid-19. To make an accurate statistical estimate this outlier will be excluded from the sample.

There are also some observations that are missing from the multiple linear regression models. The only data available on Korea's trade openness is from the period between 1995 and 2022. In addition to this data on the quality of political institutions only encompasses the years: 1996, 1998, 2000 and 2002 to 2022. This causes the model specifications that include these variables to have less observations than the baseline model.

IV. Methodology

To estimate the association between R&D investment intensity and high technology exports a multiple linear regression will be used with the absolute value of high technology exports in billion US$ as the endogenous factor and R&D investments intensity as the exogenous factor. Because the literature on the determinants of high technology exports is still inconclusive, the usage of a multiple linear regression allows for a large number of regressions to be performed to assess the changes in the estimate for the main variable of interest using multiple model specifications. Using a multiple linear regression will also yield a clear interpretable result for the association between R&D investments intensity and the absolute value of high technology exports in South Korea between 1991 and 2022. In addition to a multiple linear regression a difference-in-difference method will be employed to make a stronger causal inference on the relationship between R&D investment intensity and the absolute value of high technology exports.

4.1 Multiple linear regression model

4.1.1 Empirical specification

To get a baseline for the multiple linear regression model the initial equation (1) regresses R&D investment intensity against absolute value of high technology exports without adding any control variables.

$$HTX_t = \beta_0 + \beta_1 R\&D_t + \varepsilon_t \tag{1}$$

Here HTX_t denotes high technology exports in billion US$ in year t. $R\&D_t$ measures gross domestic public and private R&D expenditures as a percentage of GDP and ε_t captures the error term for the observations. To isolate the association between R&D investment intensity and high technology exports as well as to improve internal validity equation (2) incorporates the control variables: FDI in thousand US$ (FDI), human capital (HC), trade openness (TO) and political institutions (PI). These factors have been proven to be determinants of high technology exports by existing literature. In addition to this, GDP in billion US$ will be added to control for changes in the underlying macroeconomic flows. The addition of these variables will help isolate any mediation effects and remove some omitted variable bias that could influence the results of equation (1).

$$HTX_t = \beta_0 + \beta_1 R\&D_t + \beta_2 FDI_t + \beta_3 HC_t + \beta_4 TO_t + \beta_5 PO_t + \beta_6 GDP_t + \varepsilon_t \tag{2}$$

Equation (3) includes additional control variables that should have an effect on high technology exports based on theoretical literature but for which there is limited proof in empirical research.

$$HTX_t = \beta_0 + \beta_1 R\&D_t + \beta_2 FDI_t + \beta_3 HC_t + \beta_4 TO_t + \beta_5 PI_t + \beta_6 GDP_t + \beta_7 LnWGDP_t + \beta_8 WCON\_JP_t + \beta_{10} POP\_growth_t + \varepsilon_t \tag{3}$$

In this equation $LnWGDP_t$ denotes the natural logarithm of world GDP. $WCON\_JP_t$ is a variable created by dividing Korean hourly wage levels with Japanese wage levels that same year. This shows the convergence in hourly wage between Korea and Japan. Lastly POP_growth_t denotes the percentage growth of the South Korean population in year *t*. This variable works as a proxy for the growth of the size of the Korean internal market.

Some studies on the effects of public- and private R&D expenditure make use lagged variables that take the level of R&D investments from a few years back to measure their effect on dependent variables. An example of one of these studies is the one by Sandu and Ciocanel (2014). The reason for using lagged variables of R&D investment is that these studies argue that R&D investment has a delayed effect. In research by Tubs (2015) on the relationship between R&D and business performance, he discusses that among other factors product development time causes R&D investment to only affect business performance after a few years. To investigate if using lagged R&D investment intensity as the explanatory value yields different results this study again performs a baseline regression and a regression with control variables equal to equation one and two respectively, swapping R&D investment intensity for a lagged version. In accordance with research by Artz et al. (2010) this study uses a three-year lag. In equations four and five $R\&D_{t-3}$ denotes R&D investment intensity three years prior to year t.

$$HTX_t = \beta_0 + \beta_1 R\&D_{t-3} + \varepsilon_t \tag{4}$$

$$HTX_t = \beta_0 + \beta_1 R\&D_{t-3} + \beta_2 FDI_t + \beta_3 HC_t + \beta_4 TO_t + \beta_5 PO_t + \beta_6 GDP_t + \varepsilon_t \tag{5}$$

Analyzing the effects of three-year lagged R&D investment intensity on high technology exports will also help to reduce the risk of measuring reverse causality. This is important because it could be argued that higher high technology exports can improve a company's turnover giving it greater means to invest more in R&D. Alternatively it could be argued that higher exports expose a company to higher competitive pressure forcing it to spend more on innovation to stay ahead.

4.1.2 Diagnostic tests and robust standard errors

After establishing the main specifications, this study performs several diagnostic tests to check the robustness of the results. First a Breusch–Pagan/Cook–Weisberg test is applied to the regressions to test for heteroskedasticity. A variance inflation factor is applied to check for multicollinearity in the coefficients. Then a Durbin-Watson Test is applied to test for autocorrelation and a Ramsey RESET test is used to look for problems of misspecification. Finally, the regression analysis will be done robust to address for potential problems of autocorrelation and normality of errors among other things.

4.2 Difference-in-differences model

The purpose of this research is to analyze the potential causal relationship between Korea's R&D investment intensity and the absolute value of its high technology exports. This study foresees that there could be problems in obtaining a causal inference using the multiple linear regression model. The strength of a countries international competitive advantage is determined by a large number of factors (Porter, 1998). It is implausible for a multiple linear regression model to incorporate all general underlying economic trends, important macroeconomic events and country specific factors that influence high technology exports. Thus, it is inevitable that the multiple linear regression model will suffer from omitted variable bias.

To make a stronger argument for a causal relationship between the R&D investment intensity and high technology exports, this study will employ a difference-in-differences method to investigate a quasi-natural experiment in Korea. In September of 1999, the government of Korea launched a long-term strategic initiative called: "The Long-term Vision for S&T Development Towards 2025". This policy reform came as a direct response to the Korean IMF crisis in 1997 to 1998 with the goal of reforming the state of science and technology in the country. The content of the policy induced an exogenous pressure on national R&D levels as a percentage of GDP creating a quasi-natural experiment (Bartzokas, 2008).

4.2.1 Policy background

Before the enactment of "The Long-term Vision for S&T Development Towards 2025" there were already some policies instated that affected R&D investments by private and public institutions. Table 4 gives a summary of the political situation before 1999 to show the distinct differences before and after the enactment of the policy.

Table 1, Chronological overview of important South Korean policies on R&D investment:

Date	Policy name	Contents
1966	Korea Scientific Procedure Research Center Promotion Act.	Formation of the Korean institute of science and technology (KIST). KIST functioned as the first public research institute conducting R&D.
1967	Government organization act.	Formation of the ministry of science and technology (MOST).
1972	Technology Development Promotion Law	Establishing funding for national research initiatives to support industrial technological learning, and funding university R&D.
1973	Heavy and Chemical Industries Promotion Plan.	Industry politics promoting the formation of HCI's with the goal of reaching a target of 10 billion dollar annual exports by the early 1980s with the share of HCIs in total over 50%.
1973		Establishment of reserve fund for R&D activities.
1979		Establishment of the Daedeok science park with the goal of exploiting agglomeration benefits in technological development.
1980		Tax exemption for R&D and training expenses.
1981	Amendment on the Technology Development Promotion Law	Establishment of tax incentives focused on promoting private led R&D incentives in small to medium sized firms (SME's) with the goal of shifting from public led innovation to private led innovation.
1985		Formation of the largest government funded national research institute specializing in ICT, ETRI. This institution had the goal of stimulating the shift to endogenous high technology development through national research initiatives and increasingly though cooperation with the private industry.
1999	The Long-term Vision for S&T Development Towards 2025	

Sources: (Bartzokas, 2008; Jung & Mah, 2013)

"The Long-Term vision for S&T Development Towards 2025" was the first long-term government directive that tried to influence the development of science and technology in Korea (Ministry of Science and ICT, n.d.). One important goal for the long-term vision was to place the Korean scientific competitive levels on equal footings with those of the world's leading economies. The directive specifies standing out as a major R&D promoting country in the Asia-Pacific region as an important part of fulfilling that goal. In the directive the government commits itself to increasing R&D investment intensity from roughly 2% in 1999 to 3% by 2007 (Bartzokas, 2008). To do so, this the vision introduces a number of government policies that where focused on increasing the gross national public and private spending on R&D. First the government introduced measures for stimulating technical start-ups like direct technical assistance and financial assistance in the form of subsidies for employing R&D personnel and an easing of regulations. This is because mostly the small to medium-sized enterprises drive innovation. These companies are very innovative since they are still heavily competing for market share. The government also introduced measures that focused on public R&D spending like increasing the government budget for science and technology initiatives to 20% in 2004 and 25% to 2007 (Bartzokas, 2008). The government also introduced policies that improved the availability of qualified workers like through the expansion of educational initiatives. Lastly the government introduced a number of policies aimed at improving the cooperation between government, universities, and businesses. An extensive look at the plans that were introduced in “The Long-Term vision for S&T Development Towards 2025” can be found in the appendix.

4.2.2 Sample selection and model specification

This study uses data on high technology exports between 1991 and 2021 from The World Bank dataset. South Korean data is characterized as the treatment group. For the control group this study uses data from Singapore. The outlier observation from 2022 is excluded from the sample. Between 1991 and 2021 Singapore has had a very similar economic structure and development level to South Korea, especially if you take into consideration that Korea's high technology manufacturing sector is mostly concentrated in the more developed urban areas of the country. Like Korea, Singapore is one of the four Asian tiger economies. This is a group of economies that saw rapid economic development and industrialization during the same period (Sarel, 1996). The difference-in-differences model is denoted in equation (6).

$$HighTechExports_{it} = \alpha + \delta Time_t + \gamma Treat_i + \beta(Time_t \times Treat_i) + \epsilon_{it} \tag{6}$$

Here $HighTechExports_{it}$ denotes the absolute value of high technology exports for unit *i* at time *t*. $Time_t$ is a time dummy variable that takes the value of *1* if an observation is from after the natural experiment (1999 and following years) and *0* if not. $Treat_i$ is a binary variable that takes the value *1* if an observation belongs to the treatment group and *0* if an belongs to the control group. $Time_t \times Treat_i$ gives the treatment effect for the difference-in-difference estimator this is the coefficient of interest. Finally, ϵ_{it} denotes the error term for unit *i* at time *t*. In addition to the baseline model, equation (7) adds the control variables FDI, human capital (HC) and GDP. FDI and human capital are relevant control variables because empirical literature has reached a consensus that these variables are determinants of high technology trade. GDP is added to control for underlying economic fluctuations that influence high technology exports. The addition of these variables should improve the isolation of the estimate making it more accurate at measuring the effect of the policy introduction on high technology trade. The extended difference-in-difference model is denoted by equation (7).

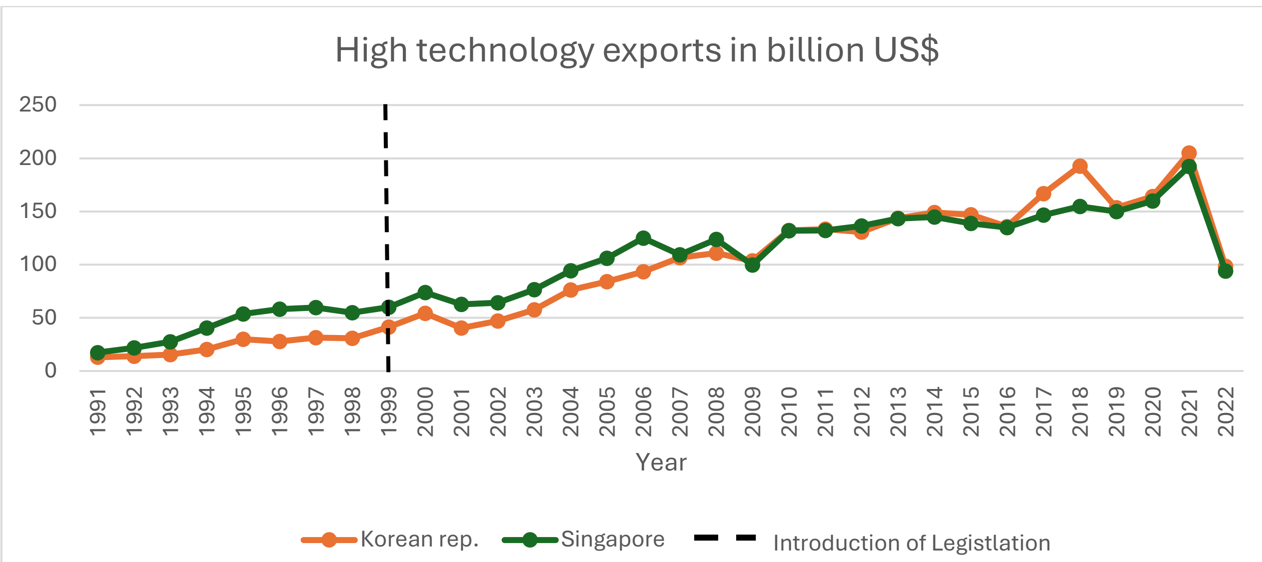
$$HighTechExports_{it} = \alpha + \delta Time_t + \gamma Treat_i + \beta_1(Time_t \times Treat_i) + \beta_2 FDI_{it} + \beta_3 HC_{it} + \beta_4 GDP_{it} + \epsilon_{it} \tag{7}$$

In this equation FDI_{it} denotes the foreign direct investment for unit *i* at time *t*. HC_{it} denotes the average years of schooling for an individual above the age of 25 for unit i at time t. GDP_{it} gives the gross domestic product for unit *i* at time *t*. In the section on other determinants of high technology exports this study discusses the quality of political institutions as well as trade openness as two factors that have also been empirically proven to have a statistically significant effect on high technology exports. However, due to the lack of data on these variables in the pre-treatment period they have been excluded from the model specification. A model that includes these variables can be found in the appendix.

4.2.3 Parallel trends assumption and diagnostics test

To test for the parallel trends assumption this study does a visual analysis of the high technology exports for Korea and Singapore before the introduction of legislation. Figure 2 shows the plotted line for high technology exports in Korea and Singapore between 1991 and 2022. Analyzing this figure shows that before 1999 the trends in high technology exports in Korea and Singapore greatly overlapped and only saw minimal deviations. Because of this we can conclude that the parallel trends assumption holds.

Figure 3, high technology exports in billion US$



(Trading Economics, n.d.-b)

This study also performs a diagnostic test on the difference-in-difference estimator. Since the model is based on a small number of observations a Breusch-Pagan test will be performed to analyze the possible presence of heteroscedasticity.

V. Results

5.1 Multiple linear regression model

Table 4 reports the results from the multiple linear regression models one to three. Model one is the baseline model and only regresses R&D investment intensity against the absolute value of high technology exports. The obtained estimate for the association has a positive sign and is statistically significant at the 1%. Model two adds five control variables to the baseline model. Focusing on the estimate for the effect of R&D investment intensity, model two finds that adding control variables reduces the magnitude of the estimate while the sign and statistical significance remain unchanged. Model three includes all the control variables that this study suspects to influence high technology exports. Analyzing the results focusing on the estimate for the association between R&D investment intensity and high technology exports shows that the addition of these control variables further reduces the magnitude of the estimate. The sign of the measured estimate remains positive, but the statistical significance drops to 10%. Interpreting the estimate for R&D investment intensity in model three shows that a 1% increase in R&D investment intensity increases high technology exports by roughly twenty billion. This magnitude exceeds the magnitude for the estimate found in empirical literature (Sandu & Ciocanel, 2014). The R-squared value throughout all models: one, two and three lies between 0.9 and 1, suggesting that the models have a high explanatory power. However, there could be potential problems of overfitting. The F-statistics of models one two and three are 365,66, 120,48 and 131,73 respectively. These values are high suggesting that the models have a good fit.

Table 2, Multiple linear regression model results:

	Dependent variable:		
	High technology exports		
Model	(1)	(2)	(3)
R&D investment intensity	56,222***	28,764***	20,006*
	(2,940)	(7,791)	(10,456)
GDP		0.082***	0,063**
		(0,021)	(0,028)
FDI		1,519***	1,565**
		(0,435)	(0,629)
Average years of schooling		-17,376	-13,911
		(11,072)	(12,280)
Trade openness		-1,559**	-0,971
		(0,698)	(0,697)
Political institutions		0,782	0,493
		(0,878)	(1,557)
Log value of world GDP			27,619
			(21,496)
Population growth			355,916
			(1894,478)
Wage convergence Japan			27,028
			(72,521)
Observations:	31	23	23
R^2	0,9333	0,9773	0,9786
F statistic	365,66*** df = (1,29)	120,48*** df = (6,16)	131,73*** df = (9,13)

Note: **p < 0,1 **p < 0,05 ***p < 0,01*
Robust standard error in parenthesis ("std error")

Table 3 reports the results from models four and five. These model specifications include a three-year lagged version of R&D investment intensity instead of the R&D investment intensity of the same year. Apart from the addition of a lagged R&D investment intensity, models four and five follow the same model specifications as models one and two respectively, due to that three-year lag model four has three less observations than model one. Model four regresses the three-year lagged R&D investment intensity against absolute values of high technology exports. The measured estimate for the association in model four has a positive sign and is statistically significant at the 1%. This estimate is relatively equal to the magnitude and sign from baseline model one. Model five introduces the same control variables as in model two. Focusing on the association between R&D investment intensity and high technology exports, this model confirms that the addition of control variables reduces the magnitude of the estimate for the association. The sign remains positive while the statistical significance drops to the 5% level. Interpreting the estimate for R&D investment intensity in model five shows that a 1% increase in R&D investment intensity increases high technology exports by roughly twenty billion. Just as in model one to three, the R-squared for models four and five are very high. Model four has an R-squared of 0,873 and model five has an R-squared of 0,972.

The F-statistic of models four and five are 217,46 and 103,18 respectively. From the R-squared values and F-statistics this study infers that these models have a high explanatory power and a good model fit. However, there are still risks of overfitting. Based on these results it is unlikely that the association between R&D investment intensity and high technology exports is suffering from problems of reverse causality. The results of models one to five show that the magnitude and sign of the estimate for the three-year lagged R&D investment intensity is relatively similar to the magnitude and sign for the regular R&D investment intensity. This is probably caused by the fact that there is a strong persistent underlying upwards trend in Korea's R&D investment intensity that causes a degree of autocorrelation in the time series. Because of this autocorrelation it is possible that the lagged- and non-lagged variable for R&D investment intensity might be capturing the same information. However, based on the analysis of the theoretical and empirical literature as well as the robustness checks, this study determines that model five most accurately captures the statistical estimate for the effect of R&D investment intensity on the absolute value of high technology goods. This is based on the robustness checks, the empirical literature on the control variables and the empirical literature on using lagged versus non-lagged variables for R&D investment intensity.

Table 3, Multiple linear regression model results:

	Dependent variable:	
	High technology exports	
Model	(4)	(5)
3 year lagged R&D investment intensity	59,872*** (4,060)	19,761** (7,932)
GDP		0,106*** (0,019)
FDI		1,116*** (0,322)
Average years of schooling		-18,850 (11,424)
Trade openness		-1,585** (0,747)
Political institutions		1,596 (1,128)
Observations:	28	23
R^2	0,873	0,972
F statistic	217,46*** df = (1,26)	103,18*** df = (6,16)

Note: **p < 0,1 **p < 0,05 ***p < 0,01*
Robust standard error in parenthesis ("std error")

For the coefficient estimate of the control variables there are some consistencies with empirical and theoretical literature. First FDI is observed to have consistent statistically significant effect with a positive sign in models two, three and five. This is in line with the findings from the empirical literature (Gökmen & Turen, 2013; Seyoum, 2004; Tebaldi, 2011). Additionally, throughout all the models, growth in GDP has a positive and statistically significant effect on high technology exports. This is also in line with the theoretical literature that specifies that a higher absolute value of the total production of a nation should lead to higher exports (Leamer, 1995). Finally, some factors like political institutions, world GDP and population growth have signs that are in line with the empirical literature but that are not statistically significant. Thus, they are not completely consistent with the predictions of the literature since the empirical literature would predict these estimates to have a significant effect on high technology exports (Ferragina & Pastore, 2007; Tebaldi, 2011; Zapata et al., 2023). The estimates for these coefficients not being statistically significant could be explained by the limitations of the models namely the low number of observations. Due to the small size of the model, it is likely that some significant relationships with a smaller magnitude are not being measured by the model. It should also be noted that the magnitude of population growth is unrealistically high when looking at the practical implications. It is unlikely that a 1% increase in the population would lead to an increase in high technology exports of roughly 355 billion. This problem is likely due to population size not being an accurate proxy for internal market size. Rather, it might be correlated with underlying trends in the outcome variable.

There are also some observed coefficient estimates for control variables that do not consist with empirical and theoretical literature. To start, the empirical as well as theoretical literature specifies that an improvement in the trade openness should increase high technology exports (Gökmen & Turen, 2013; Porter, 1998; Tebaldi, 2011). However, models two and five show that trade openness has a negative effect on high technology exports at the 5% significance level. Another inconsistency is the sign of average years of schooling. This variable is a proxy for human capital and thus empirical literature expects it to have a positive sign (Ferragina & Pastore, 2007; Seyoum, 2004; Tebaldi, 2011). Contrary to this, models two, three and five show average years of schooling to have a negative effect on high technology exports. This estimate is however not statistically significant. Finaly, wage convergence with Japan should have a negative effect based on theoretical literature. This variable functions as a proxy for Korea's diminishing wage advantage compared to other industrial economies. Therefore, as wage convergence increases Korea's competitive advantage face negative pressure. The negative sign for the estimate of trade openness could be a result of the model set up. Korea's trade freedom score is almost constant throughout the time series. This makes it more difficult to find an accurate estimate for the variables effect especially in combination with the small number of observations. This could have led to the inconsistent result when comparing with the empirical literature. The inconsistency in the results for the sign of the estimate for human capital can be explained by the problems of multicollinearity. Without these problems the sign is consistent with the empirical literature as can be observed by the results from the difference-in-difference model seven.

5.1.1 Diagnostic tests and robustness checks

The results for all robustness check can be found in the appendix. Analysis of the results from the robustness checks leads to the following results. The results from the Breusch–Pagan/Cook–Weisberg tests find that all the models one through five show no signs of heteroscedasticity. The results from the Durban-Whatson tests indicate positive autocorrelation in both the baseline models one and four. Model two, three and five show no signs of autocorrelation. From the results of the Ramsey RESET tests follows that baseline models one and four encounter problems of misspecification both at the 1% significance level. This implies that there are important non-linear relationships or interaction terms that are not included in these models. The results for the RESET tests of the other models two, three and five show no signs of misspecification. Finally, analysis of the variance inflation factor shows that models two, three and five suffer with issues of multicollinearity. In model two and five results of the VIF test show issues of multicollinearity for the variables R&D investment intensity, GDP, and average years of schooling. In model three the variables for the logarithmic value of world GDP and the wage convergence with Japan also show clear indications of multicollinearity on top of the variables that already showed signs of multicollinearity in model two.

5.2 Difference-in-Difference model:

Table 4 reports the results from the difference-in-difference models six and seven. The time variable denotes the average change in the outcome variable from the pre-treatment to the post-treatment period for the control group. The treatment indicator captures the difference between the treatment group and the control group before the policy was enacted. This captures any pre-existing differences in the groups before the treatment was applied. The interaction term shows the difference-in-difference estimator. This is the variable of interest for the research that captures the effects of the policy introduction on the absolute value of high technology exports. The estimator for the treatment effect in model six has a negative sign and is statistically significant at the 1% level. Interpreting the magnitude of this coefficient indicates that before the enactment of "The Long-Term vision for S&T Development Towards 2025" the absolute value of high technology exports was on average around nineteen billion more in Singapore when compared to Korea. The time variable has a positive sign and is statistically significant at the 1% level. This variable indicates that on average the absolute value of Singapore's high technology exports post treatment is approximately eighty billion higher than pre-treatment. The interaction term in model six has a positive sign but is not statistically significant. Adding control variables in model seven changes the sign of the estimate to be negative implying that the policy had a negative effect on high technology exports. However, the estimate is still statistically insignificant. In model seven the magnitude of the treatment indicator is a lot greater but still has a negative sign and is statistically significant at the 1% level. The time variable is no longer significant, and the magnitude of the estimate is greatly reduced. All the estimates for the control variables are statistically significant with at the 1% level and consistent with findings from previous empirical and theoretical literature (Ferragina & Pastore, 2007; Gökmen & Turen, 2013; Seyoum, 2004; Tebaldi, 2011).

Table 4, Difference-in-Difference model results:

	Dependent variable:	
	High technology exports	
Model	(6)	(7)
Time variable	79,090***	5,375
	(9,164)	(7,918)
Treatment indicator	-18,811***	-80,009***
	(6,458)	(6,409)
Interaction term (Time variable x	15,436	-2,340
treatment indicator)	(13,901)	(7,570)
GDP		0,088***
		(0,008)
FDI		0,333***
		(0,103)
HC		14,403***
		(3,333)
Observations:	62	62
R^2	0,577	0,9683
F statistic	70,63*** df = (3,58)	373,66*** df = (6,55)

Note: **p < 0,1 **p < 0,05 ***p < 0,01*
Robust standard error in parenthesis ("std error")

5.2.1 Diagnostic tests and robustness check

Analyzing the results from the Breusch–Pagan/Cook–Weisberg test shows evidence for the presence of heteroscedasticity in model six at the 1% statistical significance level and for model seven at the 5% statistical significance level. This problem is solved by using robust standard errors for model six and seven. Analyzing the results from the extended difference-in-difference model that includes control variables for quality of political institutions and trade openness shows no relevant differences in the results in comparison to model seven. Results from the robustness checks can be found in the appendix.

VI. Limitations

6.1 Multiple linear regression model

This section discusses limitations in the findings of the multiple linear regression models. Some of the limitations apply to all multiple linear regression models. To start all models lack a sufficient number of observations. Data on the absolute value of high technology exports and gross domestic spending on R&D includes one observation for each year between 1991 and 2022. This low number of observations reduces the statistical power of all multiple linear regression models and increases the variability in the measurements for the estimates. The models two, three and five that include control variables suffer from an even greater lack of observations due to the missing data on the quality of political institutions in the years of 1991 to 1995, 1997, 1999 and 2001. Furthermore, all statistical models suffer from potential problems of omitted variable bias. Even though most determinants of high technology trade that are supported by theoretical and empirical literature were considered in the model specifications, there could be country specific factors or underlying economic forces that this study failed to capture. Omitted variable bias reduces the statistical accuracy of the multiple linear regression models and means that the models only capture an association and not a definitive causal estimate. Finally, the high level of the R-squared throughout all multiple linear regression models might entail problems of overfitting. This problem occurs when the coefficients in a statistical model not only represent the underlying factors that determine the outcome variable but also fit into the random fluctuations of the outcome variable. As a result, predictors for the estimates from the model are biassed. Overfitting is a bigger problem in more complex models with a small number of observations. This potential overfitting could be caused by the problems in multicollinearity. However, this would not explain the high R-squared in models one and four. Also models two and five are not overly complex and do not include many irrelevant variables. On the contrary, the relevance of the control variables in these models are substantiated by theoretical and empirical literature so it is also not implausible that the high explanatory power is legitimate.

There are also some model specific limitations. Namely the models two, three and five that include control variables suffer from problems with multicollinearity. This can lead to unstable estimates for the association and inflate standard errors leading to predictors being less statistically accurate. Increasing the sample size can help isolate the effects of individual factors reducing problems of multicollinearity in future studies. Some of the variables that suffer from multicollinearity are proxies. Future studies could experiment with different types of proxies for these effects to mitigate the problems of multicollinearity. This study's main variable of interest, R&D investment intensity, also suffers from multicollinearity. Since the coefficient estimate is statistically significant in all the model specifications, we can still interpret the magnitude and sign of the estimate. However, the magnitude will be less accurate. Models one and four also suffer from problems with robustness. Namely both models suffer from problems with autocorrelation and misspecification. However, these robustness problems disappear after adding control variables. This suggest that the problems stem from the omission of important explanatory variables. This inference is supported by the observation that the magnitude of the estimate for R&D investment intensity decreases as more control variables are added implying that the baseline model suffers from upwards bias due to the omission of other determinants of high technology trade. Due to the problems with autocorrelation and misspecification, the results from model one and four cannot be interpreted.

6.2 Difference-in-Difference model

The difference-in-difference model faces a number of limitations in the interpretation of the results. The variable of interest for this study is the interaction term or the DID estimator. One limitation of the model specification is that the estimate for this coefficient is not statistically significant in both model specifications four and five. This could be interpreted as the policy having no statistically significant effect on high technology exports. However, the model suffers from a lack of observations. Thus, this model might have problems with measuring statistically significant relationships between variables. Future research should employ a larger dataset to make a better statistical analysis of the quasi-natural experiment. The second limitation has to do with the treatment. Since "The Long-Term vision for S&T Development Towards 2025" is implemented in increments, it is harder to determine its precise effect on R&D investment intensity at any given moment. Thus, it is hard to establish how much the R&D investment intensity in Korea changed as a result of the policy introduction. Additionally, since the post treatment period lies between 1999 and 2022, it is hard to argue that the treatment measures the isolated effects of the "The Long-Term vision for S&T Development Towards 2025". More likely is that the treatment is measuring the effect of a large number of policies that were enacted around the 1997 to 1998 IMF crisis. During this period, a number of policies were introduced that affected the economic structure of Korea. These changes in the economic structure could also have affected the absolute value of high technology exports. This makes interpreting the interaction term as a causal estimate for the effect of R&D investment intensity on the absolute value of high technology exports incorrect. Future research should look for a quasi-natural experiment that was implemented less gradually to find a more isolated effect of changes in R&D investment intensity on the absolute value of high technology exports. Another limitation of the difference-in-difference model specifications is the limited size the control group. The control group only consists of data from Singapore. Using only one country as the control group makes the model more receptive to confounding variables. This means that there might be country specific differences between the treatment- and the control group that influence the outcome variables as well as the independent variables thereby skewing the relationship that is measured by the model. Using data from Singapore as the control group might be especially receptive to biases from confounding variables because one could argue that Singapore's high technology exports are for a large part related to its position as an important hub for international trade (Sandu & Ciocanel, 2014).

Future research should try to find a more diversified control group. This will be difficult since this study already considered most comparative economies in the region. However, these comparative economies did not comply with the parallel trend assumption. Finally, the study finds some problems through the robustness tests. Both models six and seven suffer from problems with heterogeneity. This paper solves these problems by regressing the difference-in-difference models using robust standard errors.

VII. Conclusion

The main research question that this study tries to answer is: *what is the effect of R&D investment intensity on the absolute value of high technology exports in Korea between 1991 and 2022?* To answer this question this study covered theoretical literature and empirical literature in order to find both the theoretical explanations for the relationship between R&D investment intensity and high technology exports as well as the empirical proof of this relationship. The hypothesis of this study is that: *R&D investment intensity has had a positive effect on the absolute value of high technology exports in Korea between 1991 and 2022.* To test this hypothesis, the study uses a multiple linear regression model in order to find an estimate for the association between R&D investment intensity and the absolute value of high technology. To make a stronger argument for a causal relationship, the study also investigates a quasi-natural experiment using a difference-in-difference method. The conclusions from these two approaches are discussed in the following sections.

The baseline multiple linear regression model one estimates the relationship between R&D investment intensity and the absolute value of high technology exports in billion US$. Subsequent models two and three added control variables based on the theoretical and empirical literary study. The models were subjected to several robustness checks and robust standard errors were used in all model specifications. From the results of these models, this study concludes that R&D investment intensity has a positive statistically significant association with the absolute value of high technology exports in Korea between 1991 and 2022. This means that higher R&D investment intensity should coincide with higher values of high technology exports in Korea. The sign of the estimate is consistent with the empirical and theoretical literature in this field. The magnitude of the estimate in this study is relatively high compared to the empirical literature. This can be explained by the fact that most existing literature is based on a panel data analysis and thus measures a more general association while this study only focusses on the association between R&D investment intensity and high technology exports in Korea. Since Korea has made R&D part of its core strategy to increase the size of its high technology sector it is reasonable to conclude that R&D investments have a stronger effect on high technology exports in Korea than in most other economies. This is substantiated by the analysis of Korea's international competitive position using Porter's diamond model. It was determined that other factors that are not related to the intensity of R&D investments can have an effect on the magnitude of the relationship between R&D investments intensity and the absolute value of high technology exports (Porter, 1998). Alternatively, the diverging magnitude could be explained by the lack of observations and the problems of multicollinearity which make the statistical estimate less accurate.

Models six and seven analyze the effects of "The Long-term Vision for S&T Development Towards 2025" to estimate the causal effect of an increase of R&D investment intensity on high technology exports. These models compare the trends in high technology exports before and after the introduction of this policy in 1999 with a control group that consisted of data from Singapore. From the results of model six this study concludes that the policy introduction had no significant effect on the absolute value of high technology exports. Model seven adds control variables for GDP, FDI and human capital to the baseline model. Model seven also finds no statistically significant effect for the introduction of “The Long-term Vision for S&T Development Towards 2025” on the absolute value of high technology exports. This conclusion seems contradictory to the empirical literature and to the empirical evidence from the multiple linear regression model. However, this unexpected result can be explained by the limitations of the difference-in-difference model as laid out in the section on limitations. Because of problems with the isolation of the effect of the policy introduction this study fails to accurately measure the effects of the introduction of “The Long-term Vision for S&T Development Towards 2025”. Thus, the study fails to make a substantiated conclusion on the causal relationship between R&D investment intensity and the absolute value of high technology exports. For this reason, the relationship remains ambiguous.

In short, this study concludes that there is a statistically significant association between R&D investment intensity and the absolute value of high technology exports in Korea between 1991 and 2022. The answer to the main research question is that an increase of R&D investment intensity by 1% is associated with an increase in the absolute value of high technology exports in Korea by approximately twenty billion. This means that this paper’s hypothesis was correct. However, due to the limitations of the difference-in-difference model this study fails to find a causal link between the variables of interest. This conclusion implies that increasing the R&D investment intensity leads to an improvement in the international competitive position of a nations high technology industries. This study finds that the association between R&D investment intensity and the absolute value of high technology exports is greater in Korea when compared to the existing literature on Europe (Sandu & Ciocanel, 2014). From this comparison, the study concludes that structural economic elements are important determinants for the yield of R&D investments. Future research should investigate what factors influence the magnitude of the relationship between the level of R&D investment intensity and the absolute value of high technology exports. From these results other economies and national industries could take away that devoting resources to R&D is an effective way of improving the exports of a nations high technology sectors. For Korea, this conclusion implies that their strategy of heavy focus on R&D is successful at improving the nation’s international competitive advantage on the high technology markets. However, an important caveat to these implications is that the magnitude of the association might not be completely statistically accurate due to the problems with multicollinearity and the small number of observations in the multiple linear regression models. Additionally, this paper failed to find a direct causal relationship between R&D investment intensity and the absolute value of high technology exports. Therefore, the implications of these results might be misleading. To resolve these issues future research should expand on the statistical model by adding more observations and experimenting with different controls to improve the statistical accuracy of the estimates. Moreover, future research should alter the model specifications for the difference-in-difference model and look for a quasi-natural experiment with a more isolated effect to find a direct causal relationship between R&D investment intensity and high technology exports. Building on the results from this research other economies with high levels of R&D investment intensity could be investigated to assess if the conclusions from this paper hold for other economies.

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Appendix

A. Data on the main variables of interest.

Table 5, High technology exports:

Year	High technology exports (billion US$ basis)	Change	Change (%)
1991	12,9	1,93	17,71%
1992	14	1,15	8,91%
1993	15,5	1,43	10,21%
1994	20,2	4,73	30,52%
1995	29,8	9,61	47,57%
1996	27,7	-2,13	-7,15%
1997	31,5	3,84	13,86%
1998	30,9	-0,568	-1,80%
1999	41,4	10,4	33,66%
2000	54,3	13	31,40%
2001	40,4	-14	-25,78%
2002	46,9	6,58	16,29%
2003	57,5	10,5	22,39%
2004	76,1	18,6	32,35%
2005	83,9	7,79	10,24%
2006	93,4	9,44	11,25%
2007	106,53	13,13	14,06%
2008	110,79	4,26	4,00%
2009	103,49	-7,3	-6,59%
2010	132,08	28,59	27,63%
2011	133,46	1,38	1,04%
2012	130,65	-2,81	-2,11%
2013	143,47	12,82	9,81%
2014	149,05	5,58	3,89%
2015	147,04	-2,01	-1,35%
2016	135,9	-11,14	-7,58%
2017	166,65	30,75	22,63%
2018	192,79	26,14	15,69%
2019	153,55	-39,24	-20,35%
2020	163,94	10,39	6,77%
2021	204,98	41,04	25,03%
2022	98,54	-106,44	-51,93%

Source: (Trading Economics, n.d.-b)

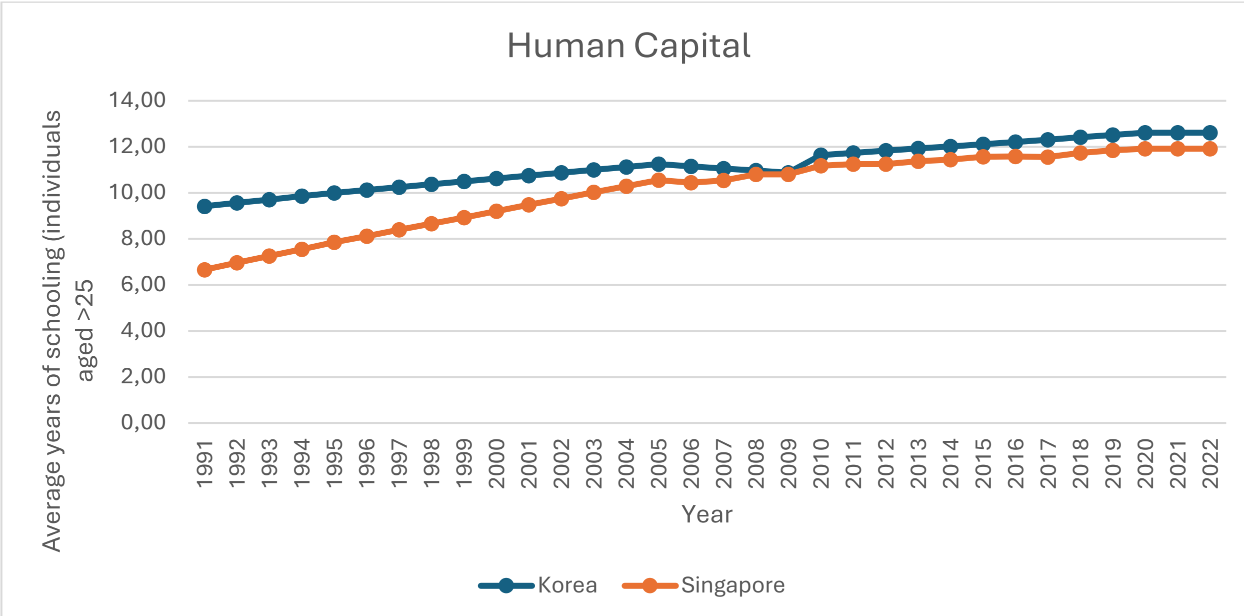
Table 6, Public and Private R&D investment:

Year	Korea GERD (%GDP)	Korea gross domestic spending on R&D (million US$ basis)	OECD GERD (%GDP)	Japan GERD (%GDP)
1991	1,71	10.062	2,06	2,63
1992	1,80	11.200	2,02	2,58
1993	1,95	13.000	1,98	2,52
1994	2,12	15.422	1,93	2,47
1995	2,16	17.231	1,96	2,56
1996	2,22	19.071	1,98	2,64
1997	2,25	20.542	2,00	2,72
1998	2,11	18.291	2,03	2,83
1999	2,025	19.475	2,08	2,85
2000	2,13	22.394	2,12	2,86
2001	2,28	25.176	2,15	2,92
2002	2,21	26.277	2,13	2,97
2003	2,28	27.957	2,13	2,99
2004	2,44	31.540	2,11	2,98
2005	2,52	33.986	2,13	3,13
2006	2,72	38.561	2,16	3,23
2007	2,87	43.097	2,21	3,29
2008	2,99	46.192	2,27	3,29
2009	3,15	49.017	2,32	3,20
2010	3,32	55.165	2,28	3,10
2011	3,59	61.963	2,31	3,21
2012	3,85	68.071	2,30	3,17
2013	3,95	72.007	2,33	3,28
2014	4,08	76.695	2,35	3,37
2015	3,98	76.922	2,37	3,24
2016	3,99	79.365	2,37	3,11
2017	4,29	88.136	2,41	3,17
2018	4,52	95.438	2,49	3,22
2019	4,63	99.971	2,56	3,22
2020	4,80	102.880	2,72	3,26
2021	4,91	110.148	2,72	3,28
2022	5,21		2,73	3,41

Source: (OECD, 2023a)

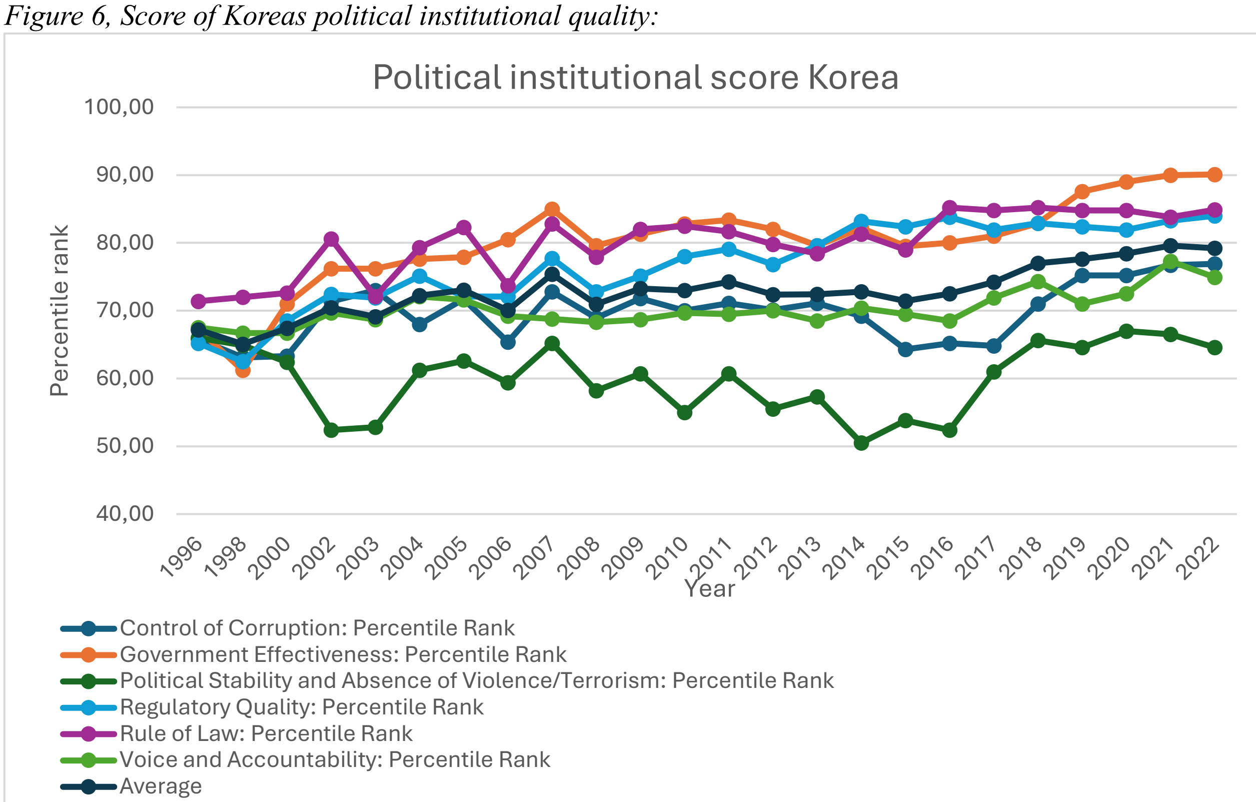
B. Data on other determinants of high technology exports

Figure 5, average years of schooling (population age > 25):



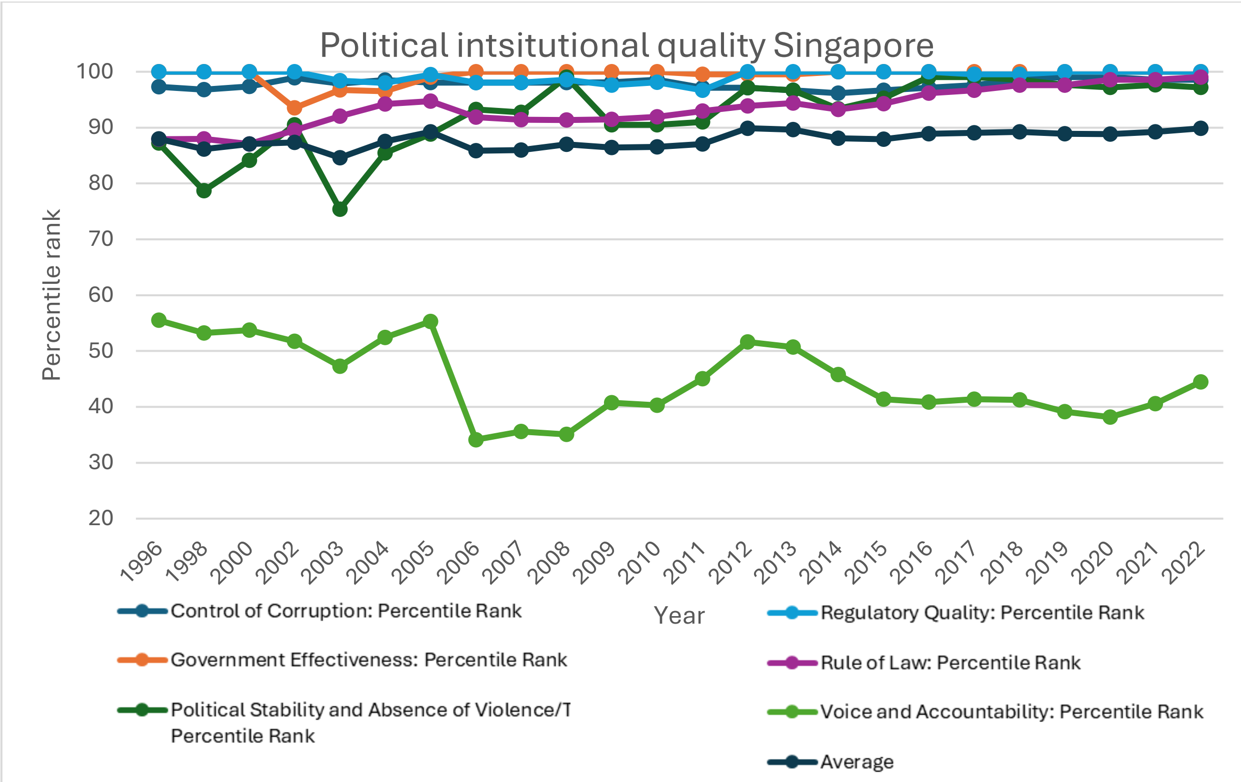
Source: (Our World in Data, n.d.)

Figure 6, Score of Koreas political institutional quality:



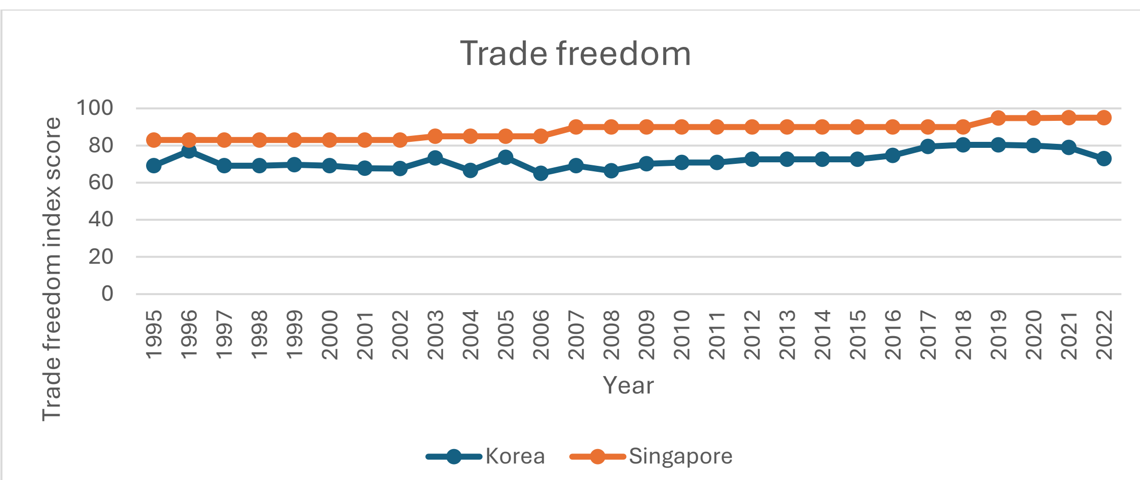
Source: (The World Bank, n.d.-b)

Figure 7, Score of Singapore's political institutional quality:



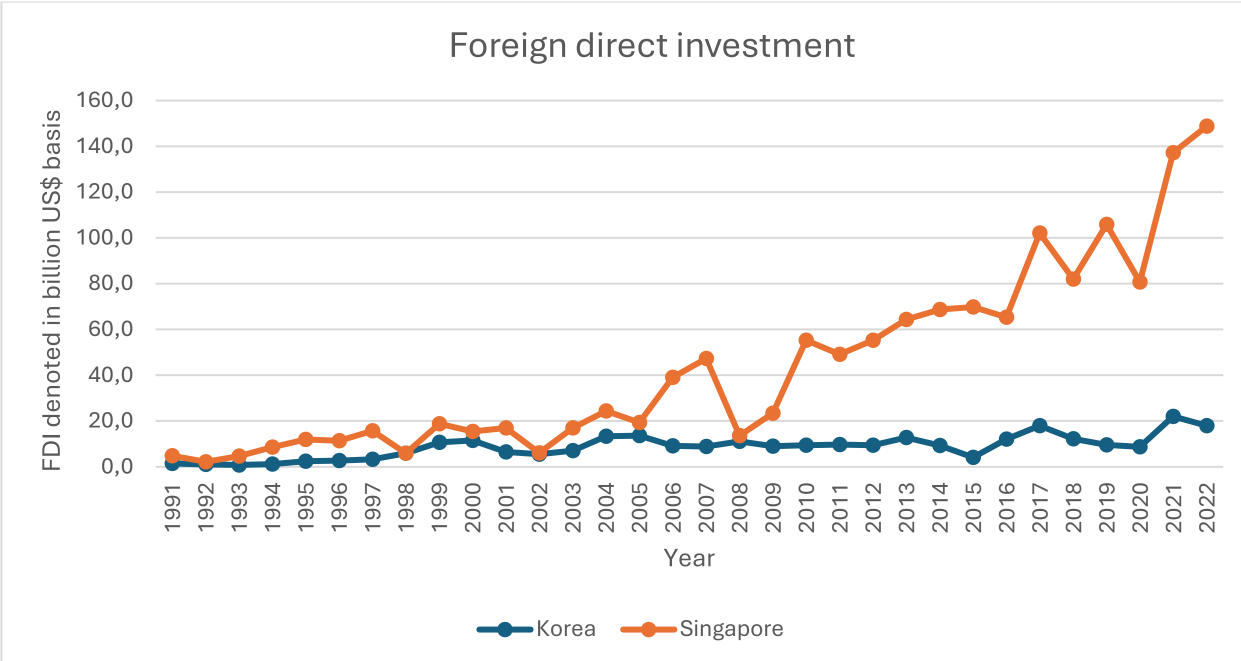
Source: (The World Bank, n.d.-b)

Figure 8, trade freedom index:



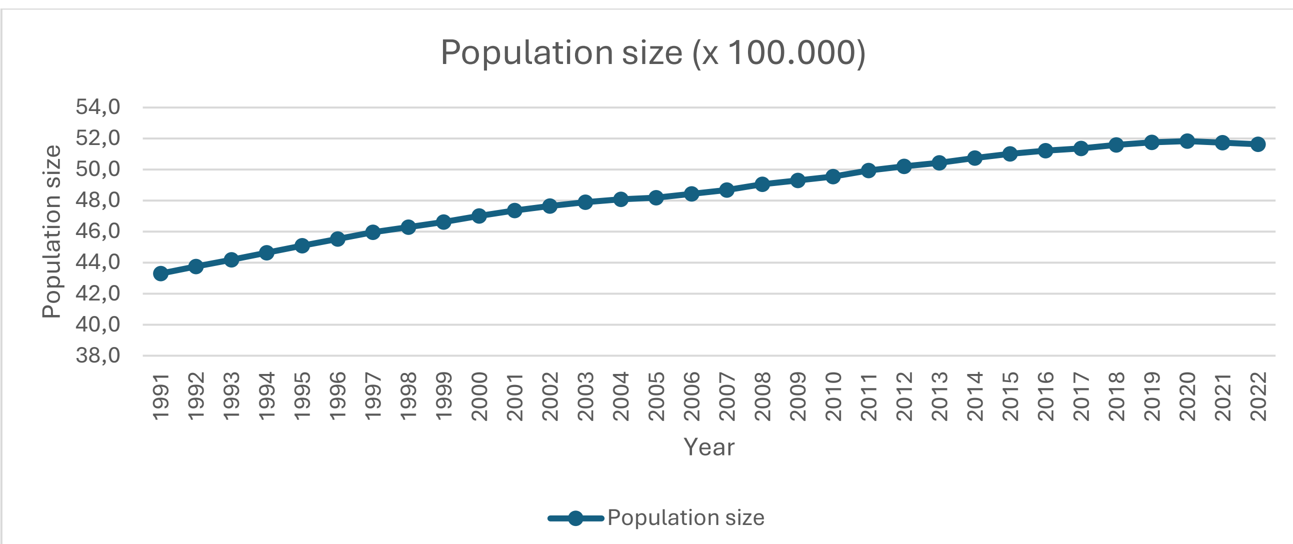
Source: (The Heritage Foundation, 2023)

Figure 9, Foreign direct investment:



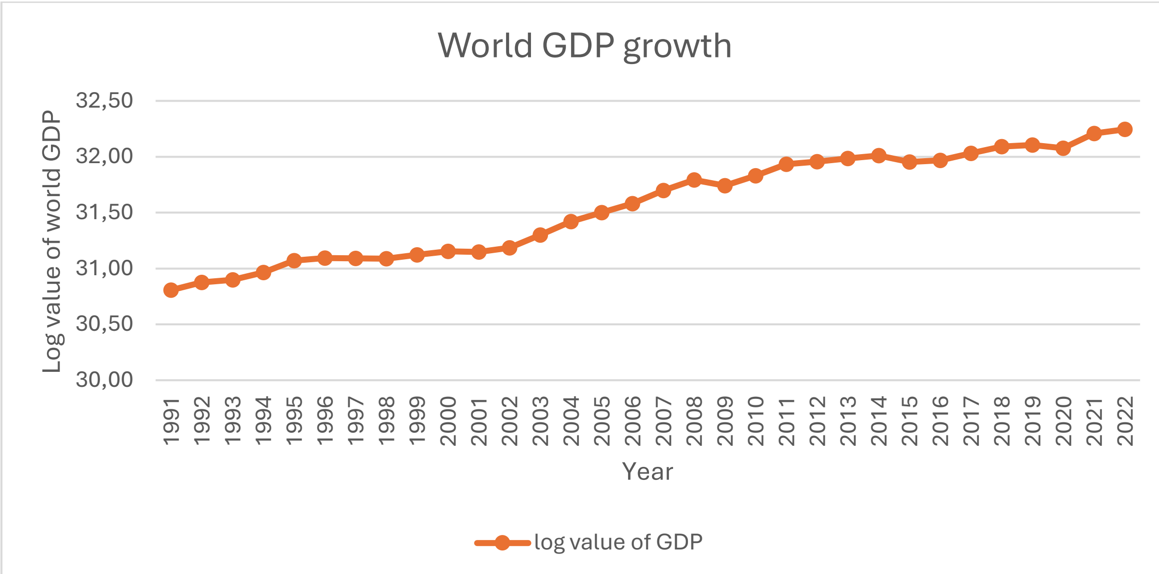
Source: (The World Bank, n.d.-a) (The World Bank, n.d.-f)

Figure 10, Korean population growth:



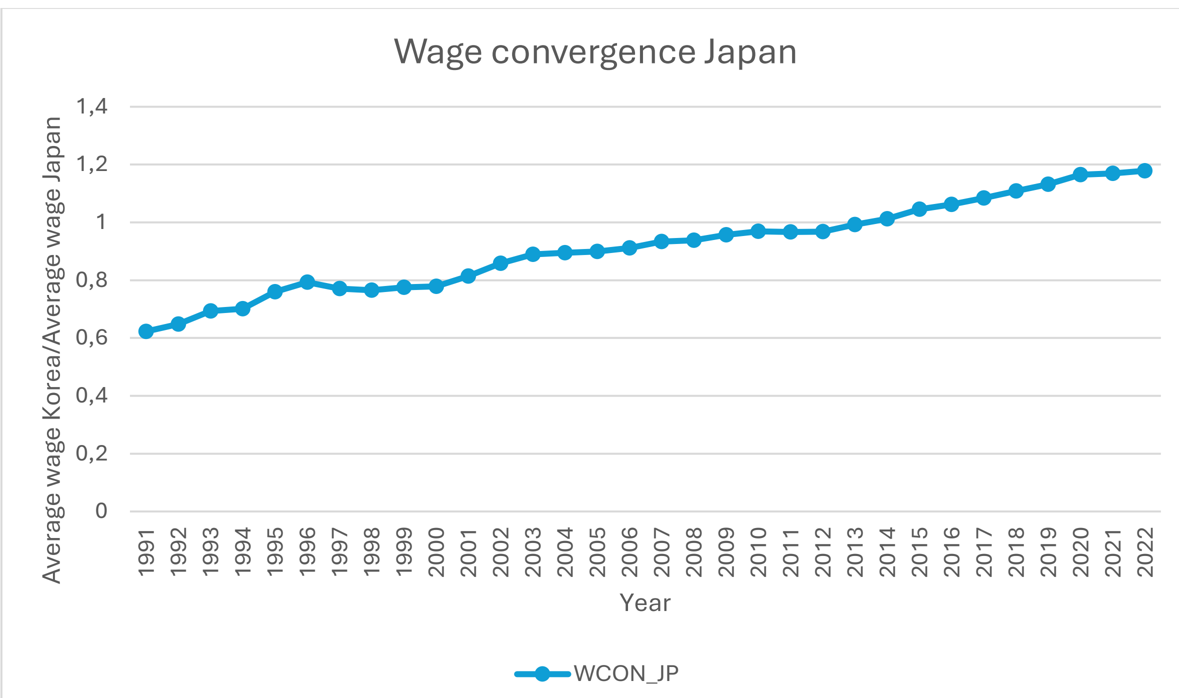
Source: (The World Bank, n.d.-d)

Figure 11, Growth of world GDP:



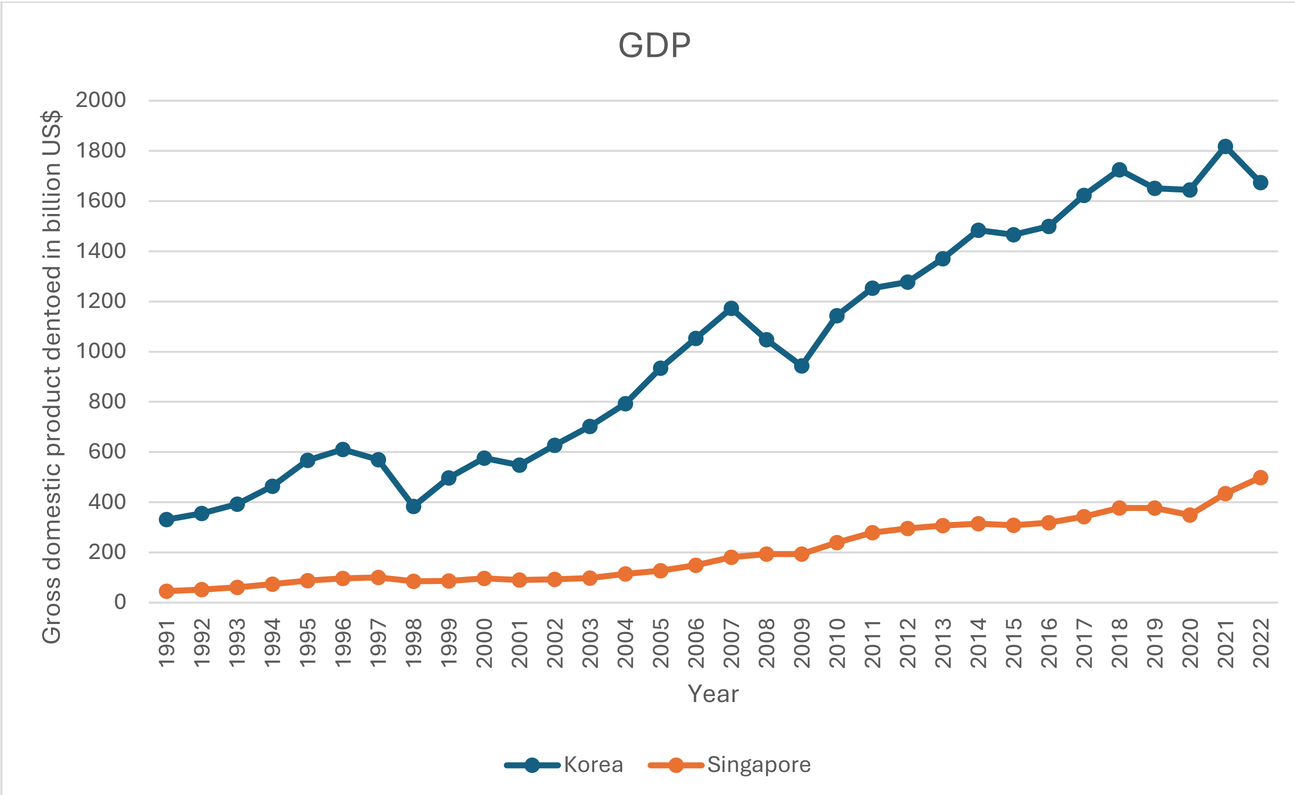
Source: (The World Bank, n.d.-c)

Figure 12, wage convergence Japan:



Source: (OECD, 2023b)

Figure 13, GDP:



Source: (The World Bank, n.d.-c)

C. Robustness checks on the multivariable regression

Table 7, Breusch–Pagan/Cook–Weisberg test model (1):

Variables: fitted values of high technology exports	
H0: constant variance	
Chi2(1)	0,42
Prob > chi2	0,516

Table 8, Durbin-Whatson test model (1):

Durbin–Watson df	(2,31)
Durbin–Watson d-statistic	0,915

Table 9, Ramsey RESET Test model (1):

Omitted: Powers of fitted values of high technology exports	
H0: Model has no omitted variables	
F (3, 26)	5,21
Prob > F	0,0060

Table 10, variance inflation factor test model (2):

Variables	VIF	1/VIF
R&D	22.95	0.043570
GDP	26.33	0.037978
Human capital	14.89	0.067155
Political institutions	3.92	0.254833
Trade openness	2.12	0.471416
FDI	1.52	0.657823
Total	11,96	

Table 11, Breusch–Pagan/Cook–Weisberg test model (2):

Variables: fitted values of high technology exports	
H0: constant variance	
Chi2(1)	1,15
Prob > chi2	0,2831

Table 12, Durbin-Whatson test model (2):

Number of gaps in sample	3
Durbin–Watson df	(7,23)
Durbin–Watson d-statistic	2,284

Table 13, Ramsey RESET Test model (2):

Omitted: Powers of fitted values of high technology exports	
H0: Model has no omitted variables	
F (3, 13)	0,02
Prob > F	0,9951

Table 14, variance inflation factor test model (3):

Variables	VIF	1/VIF
R&D	43.80	0.022832
GDP	44.52	0.022460
Human capital	21.68	0.046130
Political institutions	6.47	0.154608
Trade openness	4.94	0.202500
FDI	2.57	0.389839
Population	5.69	0.175846
Wage convergence Japan	40.70	0.024572
Log of World GDP growth	37.59	0.026603
Total	23,11	

Table 15, Breusch–Pagan/Cook–Weisberg test model (3):

Variables: fitted values of high technology exports	
H0: constant variance	
Chi2(1)	2,67
Prob > chi2	0,1025

Table 16, Durbin-Whatson test model (3):

Number of gaps in sample	3
Durbin–Watson df	(10,23)
Durbin–Watson d-statistic	2,385

Table 17, Ramsey RESET Test model (3):

Omitted: Powers of fitted values of high technology exports	
H0: Model has no omitted variables	
F (3, 10)	0,67
Prob > F	0.5895

Table 18, Breusch–Pagan/Cook–Weisberg test model (4):

Variables: fitted values of high technology exports	
H0: constant variance	
Chi2(1)	0,01
Prob > chi2	0,9368

Table 19, Durbin-Whatson test model (4):

Durbin–Watson df	(2,28)
Durbin–Watson d-statistic	0,613

Table 20, Ramsey RESET Test model (4):

Omitted: Powers of fitted values of high technology exports	
H0: Model has no omitted variables	
F (3, 23)	6,16
Prob > F	0,0031

Table 21, variance inflation factor test model (5):

Variables	VIF	1/VIF
Lagged R&D	14.95	0.066889
GDP	19.35	0.051680
Human capital	16.86	0.059316
Political institutions	4.58	0.218567
Trade openness	2.43	0.411980
FDI	1.48	0.673924
Total	9,94	

Table 22, Breusch–Pagan/Cook–Weisberg test model (5):

Variables: fitted values of high technology exports	
H0: constant variance	
Chi2(1)	1,42
Prob > chi2	0,2335

Table 23, Durbin-Whatson test model (5):

Number of gaps in sample	3
Durbin–Watson df	(7,23)
Durbin–Watson d-statistic	1.835

Table 24, Ramsey RESET Test model (5):

Omitted: Powers of fitted values of high technology exports	
H0: Model has no omitted variables	
F (3, 13)	0,17
Prob > F	0,9143

Robustness checks on the difference-in-difference estimate

Table 25, Breusch–Pagan/Cook–Weisberg test model (6):

Variables: fitted values of high technology exports	
H0: constant variance	
Chi2(1)	8,73
Prob > chi2	0,0031

Table 26, Breusch–Pagan/Cook–Weisberg test model (7):

Variables: fitted values of high technology exports	
H0: constant variance	
Chi2(1)	3,06
Prob > chi2	0,0804

D. The Long-Term vision for S&T Development Towards 2025

The following summary gives an extensive look at the policies introduced by "The Long-Term vision for S&T Development Towards 2025" that are relevant for increasing the R&D investment intensity in Korea.

"1. Measures to upgrade the innovation capacity of industry, universities and government research institutes.

- Boost R&D spending to 3% of GDP by 2007 by providing effective tax incentives to the business sector. ·
- Foster 10 000 innovation-driven SMEs through technical and financial assistance, subsidies for employing R&D personnel, and an easing of regulations (e.g., on land use, environment) on start-up companies. ·
- Increase basic research from 20% of the government R&D budget in 2004 to 25% by 2007, and raise the share of R&D that is performed in universities from 10% to 15% of total R&D over the same period. ·
- Enhance organisational flexibility and labour mobility in the GRIs, and expand their autonomy. ·
- Implement deregulation of such measures as the ceiling on chaebol shareholding and building controls in the capital region to promote business innovation activities in high-technology areas.

2. Measures to raise the efficiency of R&D investment and to secure highly qualified workers

- Raise the allocative efficiency of R&D investment by concentrating national R&D programmes on basic/generic research areas and by minimising the overlap between public and private spending. ·
- Nurture S&T manpower and minimise mismatches in the job market for skilled workers by strengthening the monitoring of demand and supply. ·
- Make engineering and vocational education more responsive to technology and business demand. ·
- Secure talented science and engineering students by expanding incentives at the tertiary level and reforming

(…)

4. Measures to upgrade the performance of the innovation system · Strengthen linkages among business, government and universities. ·

- Fortify international collaboration, and establish an East Asia regional R&D hub in Korea. ·
- Construct a national information system for S&T by 2008. ·
- Establish a performance-oriented evaluation and management system. ·
- Strengthen the roles of the NSTC and MOST in co-ordinating S&T policies and allocating their budgets." (Bartzokas, 2008, p.11-12)

E. Results from the extended difference-in-difference model specification

$$HighTechExports_{it} = \alpha + \delta Time_t + \gamma Treat_i + \beta_1(Time_t \times Treat_i) + \beta_2 FDI_{it} + \beta_3 HC_{it} + \beta_4 GDP_{it} + \beta_5 TO_{it} + \beta_6 PO_{it} + \epsilon_{it} \quad (7)$$

Table 28, extended Difference-in-Difference model results:

	Dependent variable:
	High technology exports
Model	(7)
Time variable	11,291
	(12,205)
Treatment indicator	-74,200**
	(28,368)
Interaction term (Time variable x treatment indicator)	-9,122
	(14,224)
GDP	0,094***
	(0,014)
FDI	0,379***
	(0,138)
HC	10,855
	(6,497)
TO	-0,489
	(0,665)
PI	0,629
	(0,999)
Observations:	46
R^2	0,9455
F statistic	167,91*** df = (8,37)

Note: **p < 0,1 **p < 0,05 ***p < 0,01*
Robust standard error in parenthesis ("std error")

Table 15, Breusch–Pagan/Cook–Weisberg test extended difference-indifference model:

Variables: fitted values of high technology exports	
H0: constant variance	
Chi2(1)	0,11
Prob > chi2	0,7377