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Master Thesis International Economics

# Determinants of National Export Competitiveness in the Information and Communication Technology Industry

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## Abstract

This thesis uses an augmented Gravity Model of international trade in order to identify the effect of four main variables on export competitiveness in the Information and Communication Technology (ICT) Industry. These variables are Research and Development (R&D) Intensity, R&D Spillover, Human Capital and ICT Infrastructure. Exports of manufactures and services are examined for OECD countries from 2009-2017. For service trade, investments into R&D are the most significant positive determinant out of the investigated key variables. Manufacture exports, on the other hand, are more sensitive to improvements in human capital and technological infrastructure. This thesis contributes to the literature on national competitiveness in the trade of high-technology goods by analyzing the effects of changes in the endowments of the exporting and importing nation.



Keywords: ICT, Information and Communication Technology, Competitiveness, Bilateral Trade

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# 1 Introduction

Out of all the innovations of the last decade, the advances in personal computing and consumer electronics, most notably the smartphone, have had the largest impact on the way we communicate, work, and experience life. These changes are reflected by shifts in the composition of modern service and manufacturing industries, where the Information and Communication Technology (ICT) sector is a vital and growing employer and producer. For member states of the Organization for Economic Co-operation and Development (OECD), the ICT sector accounted for 4.5 percent of value added in 2015, 80 percent of that was generated by the ICT Service sector (OECD, 2017). Additionally, ICT trade contracted relatively less following the Global Financial Crisis of 2008, allowing it to secure a growing share of total service and goods trade.

Apart from its contribution to output, a strong domestic ICT sector also contributes to productivity growth via technology diffusion. Pilat & Lee (2001) and Jorgenson et al. (2008) show that the use of ICT technology and a competitive ICT sector are important factors for national income growth. While the ICT sector shows an above-average productivity increase, desirable technology diffusion into less ICT-intensive sectors can be constrained by a lack of skilled workers (Pilat & Lee, 2001). For the case of Europe, Dahl et al. (2011) find that the productivity gains of the European ICT producing industry in the second half of the 1990s match those of the United States, while the other European industries underperformed in comparison.

It is, therefore, no surprise that a plethora of political initiatives to further increase global connectivity exists, e.g. via investments into 5G networks or funding of research in artificial intelligence technologies. The majority of OECD countries is investing in several programs to foster innovation and exports of ICT products (OECD, 2017).

This thesis aims to identify key variables that positively affect the export of ICT goods and services. To achieve this goal, recent datasets of ICT goods and services export flows in the OECD are examined. The explanatory model of these trade flows is based on an evaluation of previous empirical analyses of high-technology trade and theoretical and empirical works on one of the most important bilateral trade models, the Gravity Model. Within this model, the effects of four main explanatory variables are analyzed: Research and Development (R&D) intensity, R&D spillover, human capital and ICT infrastructure. The effects of these variables are estimated using a fixed-effects regression model, which includes the explanatory variables usually found in gravity-based models as well as a country-pair interaction effect. The results vary depending on the analyzed sector: For ICT service exports, R&D intensity is the most significant positive determinant out of the main explanatory variables. On the other hand, human capital and ICT infrastructure have the most significant positive effect on ICT manufactures exports.

This thesis is structured as follows: The next section will present theoretical and empirical analyses of international competitiveness and bilateral trade. Section 3 will show the regression model, variables and data, after which section 4 will present and discuss the empirical findings. Section 5 will contain some robustness checks, which are followed by concluding statements in section 6.

# 2 Literature Review and Trade Theory

## 2.1 Literature Review: International Competitiveness

Many political initiatives to increase production and exports of ICT goods and services are based on the idea that technology improvements create a competitive advantage for the targeted nation. National competitiveness, in that sense, is not merely the ability to produce a certain good or deliver a certain service at a lower price than others, as a higher relative price and an increasing market share are not necessarily a contradiction (Fagerberg, 1996). Hence, non-price-influencing factors, of which some are unobservable, play a role in the determination of a nations' international competitiveness. In general, there are three theoretical approaches to explaining how market shares are allocated for technology-intensive goods. The first theory is based on the Heckscher-Ohlin model of trade due to relative factor endowments. Following this "neo-endowment" (Wakelin, 1998, p. 1336) theoretical model for a two-country setting, the country which is relatively better endowed with innovation-generating factors, such as knowledge and (human) capital, will be the one producing and exporting the majority of high-technology goods. (Fagerberg, 1996)

A different theoretical model views technological differences between developed nations as the primary cause of trade (Wakelin, 1998). Fagerberg (1996) views the technological innovation capability of manufacturers as the means to shape foreign income elasticity for one's product, which he also observed when empirically analyzing the market shares and R&D expenditures of 15 OECD countries for a period from 1960 to 1983. This view of competitiveness through technology is also shared by the North-South models, in which a high-wage high-innovation geographical north has to constantly innovate to compete against the technologically catching up geographical south that is more price competitive due to lower wage levels. The trade-inducing technological advantage can be assumed as given or be endogenously modeled as a function of R&D investments and income. According to these models, high-income countries with large domestic markets that invest a relatively large proportion of their income in R&D will specialize in the production and export of high-tech goods, which in turn accelerates their growth further due to internal spillover effects. (Fagerberg, 1996)

More recent models of international trade focus on productivity and innovation at the firm level. These are based on the work of Krugman (1980), who explains trade between industrialized nations by introducing positive returns to scale and consumer love-of-variety into a two-country model with labor being the only factor of production. The combination of these assumptions implies that each firm fully specializes in producing a single variety. The model has been expanded by Melitz (2003), who added heterogeneity in productivity for the firms in the model. To export, a firm has to exceed a productivity threshold, which is dictated by the variable and fixed costs of exporting as well as the factors that also influence the threshold of domestic production, which is lower than the exporting threshold. These factors are the revenue of a given productivity, elasticity of substitution between goods and the fixed costs of production. In his model the productivity parameters are drawn randomly and cannot be influenced by the firm. Constantini & Melitz (2008) expanded the model to relax the assumption of fixed firm productivity and to allow for innovation. In addition to a stochastic development of firm productivity in each period, firms have the option to innovate once, which results in a draw from a more favorable distribution with a positive expected value of productivity growth. In order to achieve this, firms have to be able to stem the stochastic sunk costs. The model leads to several key conclusions regarding innovation and exports. First, more productive firms are more likely to innovate and to export. Second, the costs of trading dictate whether firms which are productive enough but have not innovated yet decide to pay the sunk costs of exporting or those of innovating. If trade costs are high, firms prefer to innovate so that they are able to serve the domestic market at a higher productivity. Third, firms that innovate are more productive than their non-innovative counterparts.

The established links between productivity, innovation and exports have also been researched empirically. Wakelin (1998) analyzed bilateral export flows of manufactures for a set of highly developed OECD countries. The examined trade flows all occurred in 1988, while the independent variables were formed as averages of the eight previous years in order to exclude business cycle effects. She found a significant positive effect of innovation (proxied by R&D expenses and patent statistics) on export performance, which was calculated as the ratio of exports in a bilateral setting. The introduction of country and sector fixed effects did not have a significant impact on the estimates. Furthermore, the author tried to identify separate coefficients for each country to analyze their "innovation profiles" (Wakelin, 1998, p. 1339), but had to reject the model. The rejection implies a similar sensitivity to innovation for all analyzed countries, which also account for the majority of trade flows that are inspected in this thesis. However, separating the flows by industry showed significant differences in competitiveness factors. A surprising result of this separation is that the sectors that are the closest to the manufacturing sectors investigated in this thesis, "Computers and Office Machinery" as well as "Electronics", showed a highly significant negative correlation between (national) R&D expenditures and export performance. Wakelin explained this with the broad classification of products within the categories, which leads to an amalgamation of more and less technologically intensive products in a category. Although she identified a few only medium-technology sectors, such as chemicals and machinery, as net innovation producers, it is possible that the inclusion of lower-technology goods in the ICT-related categories created those results.

Becker & Egger (2013) analyzed survey data on German manufacturing firms to estimate the impact of innovation on the propensity to export. The authors distinguished between process and product innovation and found that the latter has a stronger positive impact on the propensity to export. Also, the authors identified two key impediments to firm innovation: lacking cooperation with public research institutes and lack of own or outside capital.

For emerging markets, Dai et al. (2019) investigated the impact of firm innovation on the export survival of firms. Rather than focusing on R&D input variables such as expenditures, they analyzed a firms' value of newly introduced products. Their analysis of a dataset on Chinese firms ranging from 2000-2010 showed a positive effect of innovation efforts on the export survival probability of firms, albeit the positive effect only applies for direct exporters. Indirectly exporting firms are generally assumed to exhibit lower productivity, rendering them unable to stem the higher fixed costs of exporting. These less productive firms are found to lower their chances of survival by investing in R&D, although the estimated coefficients are insignificant.

Analyses that specifically target ICT exports are published less frequently. While many studies have been conducted on the importance of the ICT industry for productivity growth (see Jorgenson et al. (2008) for the US or Dahl et al. (2011) for Europe) and trade (e.g. Nath & Liu, 2017), there are fewer studies that examine the factors which impact competitiveness of ICT firms in an international setting. Two papers provide the groundwork for the analysis of ICT exports in this thesis. The first paper was authored by Vogiatzoglou (2009), who analyzed national export specialization in three categories of ICT Manufactures: "Electronic Data Processing Machines", "Integrated Circuits and Electronic Components", and "Telecommunications Equipment". The explanatory variables are grouped into three categories. The first category includes proxies for comparative advantage factors, such as R&D and human capital. The second category is used to identify geographical and home-market effects and includes variables such as the size of the countries' manufacturing sector and ICT sector. Lastly, the third category is labeled general factors and includes structural factors such as ICT infrastructure. His analysis of 28 countries for the period from 2000-2007 reveals R&D expenditure, international market access, ICT infrastructure and manufacturing sector size as the most significant determinants of export specialization in ICT manufacturing. On the other hand, he finds cost competitiveness (proxied by the real exchange rate), human capital and multinational firm activity to be insignificant determinants of export specialization. The second paper was written by Psychoyios & Dotsis (2018) and modeled national ICT manufactures and services exports of 29 countries as a function of R&D expenses and labor productivity. Although their study is relatively recent, their period of observation reached from 2000 to 2003. The authors split their sample between EU and non-EU countries in order to investigate differences in each subsamples' sensitivity to changes in the independent variables. Surprisingly, the authors found a negative and significant effect of R&D expenses on ICT manufactures exports in the EU, while the coefficients were positive for exports from non-EU countries and ICT services from all analyzed origins. The authors attributed this to the potential inability of EU member nations to translate R&D expenses into competitiveness-enhancing innovation. In addition to that, they assumed that a part of the R&D output is used for improving productivity and therefore captured by the other variable.

While there is a high level of heterogeneity among the presented studies with regards to countries, industries and periods, they mostly coincide in a few key points. The primary observation is that the ability to innovate, with its various proxies, is a vital component in the effort to remain competitive on an international level. In addition to that, the theoretical models of comparative advantage presented earlier in the chapter also tell us that, besides a nations' endowment with competitiveness factors, competitiveness also relies on the endowment of (potential) trade partners.

## 2.2 Modeling Bilateral Trade

The competitiveness factors discussed in the previous chapter have to be embedded in a model of bilateral trade flows. Such a model has been developed by Tinbergen (1962), who modeled trade after the physical determinants of gravitational pull, mass and distance, hence calling it the *Gravity Model*. In the most basic version of the model, trade between two countries is dependent on just three factors: 1) Exporting country income, which dictates the volume of goods it is able to supply, 2) Importing country income, which regulates demand via market size and

3) Transport costs that depend positively on the distance between two nations. Written as a mathematical expression, exports can be modeled as:

$$E_{i,j} = k_0 Y_i^{k_1} Y_j^{k_2} T_{i,j}^{\ k_3} \tag{1}$$

where $k_0$ is a constant, $E_{i,j}$ denominates exports from country $i$ to country $j$, $Y$ stands for the exporters' and importers' income respectively and $T_{i,j}$ represents the transport costs (proxied by distance) for goods from $i$ to $j$. Tinbergen acknowledged that additional variables which capture cultural and economic dimensions of distance could positively affect the accuracy of the model, which led him to add dummies for free trade zones, namely the Commonwealth and Benelux states, and shared borders as positive determinants of trade flows. Over the years, additional explanatory variables that capture these dimensions of distance were added to the specification. These include geographic factors such as water access, cultural aspects such as shared language as well as historical aspects such as colonial history (Gómez-Herrera, 2013). They are added into equation (1) as a vector $\boldsymbol{G}$ of dummy variables.

$$E_{i,j} = k_0 Y_i^{k_1} Y_j^{k_2} T_{i,j}^{\ k_3} \, \boldsymbol{G}^{k_g} \tag{2}$$

While the empirical application of Tinbergen's (1962) model was generally successful, its compatibility with the existing theoretical models of international trade was an important point of research and discussion for decades (Deardoff, 1998; Gómez-Herrera, 2013).

The Gravity Models' assumption of trade impediments had to be harmonized with the Heckscher-Ohlin model of trade, especially the possibility of factor price equalization. Perfect competition with equal factor prices between two countries would make trade between them impossible since transport costs would render the imported goods uncompetitive (Deardoff, 1998). Deardoff therefore assumed that factor prizes are not fully equalized between countries. The combination of these assumptions and constant-elasticity-of-substitution preferences led to an outcome in which each good is only produced by one country. The model of trade in this outcome conforms with the Gravity Model, as it is positively determined by exporter and importer income, although relative to world income, and negatively determined by transport costs and distance between both nations relative to the average distance between the supplying nation and those that demand the good. (Deardoff, 1998)

$$E_{i,j} = \frac{Y_i Y_j}{Y_w} \frac{1}{T_{i,j}} \left[ \frac{\rho_{i,j}^{1-\sigma}}{\sum_h \theta_h \, \rho_{i,h}^{1-\sigma}} \right] \tag{3}$$

Equation (3) shows Deardoff's version of the Gravity Model. Apart from the addition of world income $Y_w$ and elasticity of substitution between products, $\sigma$, as determinants of exports, the model also adds the term in the squared brackets. This term shrinks with an increase of the relative distance from *i* to *j*, $\rho_{i,j}$, and rises when the average relative distance from *i* to all other demanders increases. This average relative distance is the average of $\rho_{i,h}^{1-\sigma}$, weighted by the share of world income, $\theta_h$, of each of all *H* countries. $\rho_{i,h}$ is calculated as the ratio of the distance from *i* to *h* relative to the average distance from all suppliers to *h*.

In order to account for the presence of zero-trade flows and allow for asymmetric trade flows between two nations, Helpman et al. (2008) developed a model that harmonized the Gravity Model with Melitz's (2003) model of trade under firm heterogeneity and positive returns to scale. Differences in firm productivity imply that fewer firms can export to countries in which demand is relatively lower or where the variable or fixed costs of exporting are relatively higher. This heterogeneity translated into their version of the Gravity Model, in which additional factors impact exports from *i* to *j*:

$$E_{i,j} = \left(\frac{c_i t_{i,j}}{\alpha P_j}\right)^{1-\sigma} Y_j N_i V_{i,j} \tag{4}$$

Most components of equation (1), such as the income of the importing nation and transport costs, $t_{i,j}$, are still part of this model. However, several new determinants of exports can be found in this equation. Apart from transport costs, exports are also negatively dependent on the cost per unit of input[1], $c_i$. Among the new positive determinants are the price level in the importing nation, $P_j$, and $\alpha = 1 - \frac{1}{\sigma}$, which is positively dependent on the elasticity of substitution. Additionally, the number of firms in country $i$, $N_i$, and the volume of trade between *i* and *j*, $V_{i,j}$, affect exports positively. The volume of trade equals zero if the required productivity to at least achieve zero profit by exporting to *j* is larger than the maximum productivity that can be drawn from the distribution function out of which firms draw their productivity. If it is possible for a firm to draw a productivity parameter that is sufficient to at least break even when exporting, the volume of trade is positively determined by the productivity of the exporting firms and the share of firms that are able to export.

The empirical and theoretical analyses of the Gravity Model are mostly concerned with trade in goods. Walsh (2006) investigated whether the Gravity Model is also a good fit for service trade flows by using export data of 27 OECD countries from 1999 to 2001. He estimated service export flows with the basic Gravity Model presented at the beginning of this chapter, with the standard expansions of a common language dummy, an adjacency dummy as well as a dummy for EU membership. His only modification is the replacement of GDP by GDP per capita and

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[1] Note that one unit of input does not necessarily yield one unit of output. Each firm randomly draws a parameter $a$ that measures how many inputs are needed per output. Firm productivity is therefore measured as $\frac{1}{a}$.

population size. When using OLS, his regressions yielded significant coefficient estimates with the expected signs for all variables. On the other hand, usage of the Hausmann-Taylor[2] estimation technique removed the significance from all coefficient estimates except for common language and GDP per capita of both trade partners.

# 3 Empirical Analysis

## 3.1 The Regression Method

The proper regression of a bilateral trade panel data set has been vividly discussed in the empirical literature, especially in literature on the Gravity Model. In panel data sets and for linear models, unobservable impact factors are generally controlled for by either fixed or random effects. The use of random effects only yields consistent estimators if unobservable factors that influence the dependent variable are uncorrelated with the independent variables (Gómez-Herrera, 2013; Wooldridge, 2015). This is unlikely for the setting of this paper, as the position of the business cycle or a country's current diplomatic situation might influence exports as well as research expenditures or infrastructure investments. Hence, time-invariant observable and unobservable country characteristics will be controlled for by including exporter and importer fixed effects. In addition, year fixed effects are included to control for time-specific influences (Egger & Pfaffermayr, 2003). However, Egger & Pfaffermayr argued that important aspects of the interplay between nations are omitted without the inclusion of an interaction term between countries, which will therefore be included as well for the basic regressions. Furthermore, the presence of zero values has an important impact on the model, as they would have to be excluded when log-linearizing the model, which possibly leads to selection bias (Gómez-Herrera, 2013). Fortunately, the manufacturing dataset is free of zero values due to its high level of detail. The services dataset includes a few zero values, although they account for less than 1% of observations so that they can be dropped without having to expect negative effects on the outcome. This leads to the conclusion that there is no necessity for other sample selection techniques (see Linders & de Groot, 2006). Apart from zero-values, some values of the dependent and independent variables are missing altogether, although the distribution of missing values is random, as the average GDP per capita and value of exports are nearly equal between the complete observations and those where at least one independent variable was missing.

[2] The Hausmann-Taylor model is used as an alternative to standard fixed-effects models. It aims to remove the correlation between unobservable individual effects and the explanatory variables via an instrumental variable approach. (Walsh, 2006)

## 3.2 The Model

Following the theoretical discussion in chapter 2, the model aims to explain exports of ICT manufactures and services by examining the importance of four main factors: R&D intensity, R&D spillover, human capital (HC) and ICT infrastructure. The difference between the values of the independent variables for the exporters and importers will be used to acquire an estimate of their effect on exports. The main formula for the fixed-effects regression is as follows:

$$\begin{aligned} logExports_{i,j,t} = {} & \beta_1(RNDIntensity_{i,t} - RNDIntensity_{j,t}) \\ & + \beta_2(Spillover_{i,t} - Spillover_{j,t}) + \beta_3(HC_{i,t} - HC_{j,t}) \\ & + \beta_4(ICTInfrastructure_{i,t} - ICTInfrastructure_{j,t}) \\ & + GM_{i,j,t} + \alpha_i + \gamma_j + \lambda_t + \delta_{ij} + \varepsilon_{i,j,t} \end{aligned} \quad (5)$$

The indices for the exporting and the importing nation are *i* and *j*, while *t* is the time index. $GM_{i,j,t}$ is a vector of variables that are common predictors of trade in Gravity Models. These variables are discussed in section 3.5. $\alpha_i, \gamma_j$ denote exporter and importer fixed effects respectively, which are needed to control for a country's "remoteness" or its multilateral resistance to trade (Gómez-Herrera, 2013). The time fixed effects, $\lambda_t$, are used to account for global economic conditions such as oil price shocks or business cycle position. $\delta_{ij}$ captures the previously discussed interaction effects between the importing and exporting country.

## 3.3 Dependent Variables

This paper will use panel datasets to estimate the impact of the main independent variables on a nation's export competitiveness in the ICT sector. Yearly bilateral export trade flows of several categories of ICT manufactures and services will be analyzed[3].

### ICT Services

The OECD International Trade in Services Statistic (ITSS) provides the data for the analysis of ICT Service exports. Using ITSS data, an unbalanced panel data set for 31 nations ranging from 2009-2017 was collected[4]. Following the EBPOS 2010 classification, ICT Services are subdivided into Information, Computer, and Telecommunication Services, yielding a total of 17,482 observations. All exports are free-on-board and denominated in millions of current US dollars.

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[3] All data used in this thesis is noted in yearly intervals, unless specified otherwise

[4] Per destination country exports are not reported for Mexico, Norway, Spain, Turkey and the United Kingdom, see Appendix 1 for a country list. Observations earlier than 2009 were dropped due to the unavailability of ICT infrastructure data for that time period.

As can be seen from Table 1, Computer Services account for the largest share of ICT service exports. Additionally, the table shows that all service categories exhibit a high degree of variation.

**Table 1:** Descriptive statistics of ICT service exports by sector in millions of current US-Dollars

| Service Category | Obs. | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| Total Services | 5889 | 598.731 | 3096.468 | .1 | 78813.7 |
| Telecommunications | 4327 | 145.588 | 771.663 | .1 | 14471 |
| Computer | 4844 | 407.518 | 2256.816 | .1 | 64206.6 |
| Information | 2723 | 79.862 | 460.305 | .1 | 8399 |

**Table 2:** Descriptive statistics of ICT manufacturing exports by good category in millions of current US-Dollars

| Goods Type | Obs. | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| Capital goods | 14675 | 940.429 | 5310.569 | .00005 | 225357 |
| Household consumption | 12053 | 439.019 | 4105.312 | .00002 | 191805 |
| Intermediate goods | 14715 | 1320.941 | 7141.819 | .00007 | 239855 |
| Total trade in goods | 14944 | 3685.993 | 19979.06 | .00016 | 584772 |

**ICT Manufacturing**

The data for ICT manufacturing exports is provided by the OECD Structural Analysis database. The employed dataset contains all 36 OECD member states[5], which are included as exporters and destination countries over an observation span from 2009 to 2017. The total trade in goods is divided into three categories: Intermediate Goods, Household Consumption and Capital Goods. In total, this yields 56,387 total observations for ICT Manufacturing exports. As in the Service database, all exports are free-on-board and denominated in millions of current US dollars. Table 2 presents the summary statistics for the dataset. Exports are categorized by industry and the goods categories are aggregated. Again, the statistics show a high degree of variation for all industries.

[5] For a list of states, see Appendix 2.

## 3.4 Explanatory Variables

Four main explanatory variables will be used to assess competitiveness in the ICT sector.

**R&D Intensity**

A strong majority of the studies discussed in section 2.1 show that the fast pace of technological advances in high-technological industries creates the necessity of constant investments in the research of new technologies by private firms and governmental agencies alike. For businesses in OECD countries, ICT firms account for 23% of business R&D expenses, the largest share of all industries (OECD, 2017). In this thesis, R&D intensity will be used in order to proxy for the importance that a countries' government and firms assign to the development of new technologies. The UNESCO supplies the main annual dataset for R&D intensity[6]. There, R&D intensity is described as gross domestic expenditures on R&D by firms, government, higher education and private non-profit organizations as a percentage of GDP.

**Table 3:** National R&D Intensity as a percentage of GDP

| Variable | Obs. | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| R&D Intensity | 441 | 1.825 | 1 | .31 | 4.429 |

In order to validate the data, it is compared to the R&D intensity[7] dataset from OECD Main Science and Technology Indicators. Since both datasets use the same approach, scale and definitions, data from the more limited OECD set is used to replace missing values in the World Bank dataset after comparison of the two sets. A complete set of summary statistics by country can be found in Appendix 7.3. Vogiatzoglou (2009) and Psychoyios & Dotsis (2018) both find that R&D has a significant positive impact on a country's ICT exports for the majority of cases. The effects of the importing country's technological endowment were not discussed since these papers did not use bilateral data. If R&D expenses yield a comparative advantage for the production of ICT goods and services, then trade models such as the "neo-endowment" model presented in section 2.1 predict a negative impact of importer R&D on imports since the capability to create these products would converge if the importing nation is less well endowed with knowledge capital. New Trade Theory models with firm heterogeneity, on the other hand, predict a positive effect. Productivity-enhancing effects of R&D imply a higher survival rate of firms and thereby a larger income, which, following equation (4), positively affects imports.

[6] The dataset can be found at https://data.worldbank.org/indicator/gb.xpd.rsdv.gd.zs
[7] This dataset is available at https://stats.oecd.org/viewhtml.aspx?datasetcode=MSTI_PUB&lang=en#

**R&D Spillover**

Coe & Helpman (1995) and Frantzen (2000) show that apart from domestic R&D expenditure, technology spillover via trade also affects productivity, and therefore possibly trade, positively. In congruence with the work of the authors above, R&D spillover of a given country *C* is calculated as a yearly weighted average R&D intensity of the other covered nations. This average is weighted by *C*'s imports from those countries, which act as a proxy for technological closeness following Frantzen (2000). As can be seen from the descriptive statistics, the mean value is slightly higher and the deviation is lower, which is logical given the nature of its calculation. Although the number of observations is lower, each export data point has a corresponding spillover value. A full overview of the data is given in Appendix 7.4. The effects of R&D Spillover are not investigated by either Vogiatzoglou (2009) or Psychoyios & Dotsis (2018). Several possibilities exist from a theoretical perspective: In a model with firm heterogeneity and transport costs, spillover-induced productivity gains might allow more firms to surpass the export threshold, thereby increasing exports via the extensive margin. On the other hand, if the gravitational model holds, a high spillover value implies that nearby countries are investing strongly into innovation, leading to more competition and potentially a higher export threshold, which would in return lower exports

**Table 4:** Import weighted average of foreign R&D intensity as a percentage of GDP

| Variable | Obs. | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| R&D Spillover | 375 | 2.223 | .341 | 1.46 | 3.238 |

**Human Capital**

In addition to technological innovation, a skilled workforce is necessary to stay competitive in the trade of highly technological goods. The concrete approach to modeling human capital for productivity and trade research has been a point of discussion in academic literature (Engelbrecht, 1997). Barro & Lee (1993) create a measure for human capital by estimating adult educational attainment. Unfortunately, their dataset was only released in five-year intervals, and the last update was published in 2010. For OECD countries, the use of data from the Programme for International Student Assessment (PISA) and Programme for the International Assessment of Adult Competencies (PIAAC) can be a viable alternative. Unfortunately, these studies are also not published yearly and would therefore also have to be extra- and interpolated. Another proxy for human capital that is available with a yearly frequency and will be used here is the average years of schooling an age group received in a country. The data is provided by Lim et al. (2018) for all examined countries[8]. Since the dataset does not provide an average for the entire working-age group (20-65), this paper will focus on the average qualification of the recent graduate age group, aging 25-29. Similar to R&D intensity, a higher endowment of the exporter with human capital is expected to have a positive impact on exports, while the theoretical predictions for the importing nation support both directions.

**Table 5:** Per country average years of schooling for the age group 25-29

| Variable | Obs. | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| Average Schooling | 359 | 14.239 | 1.295 | 9.139 | 16.404 |

**ICT Infrastructure**

Apart from R&D expenditure and education, the diffusion of broadband internet is an important factor for innovation in the ICT sector (Lee et al. 2016). Apart from greatly improving the speed at which firms and research institutions can communicate and exchange data, it can also allow firms in the ICT service sector to provide their services to clients more efficiently. To benefit from these positive effects, political institutions such as the European Commission strive to increase technological development with initiatives such as the Digital Agenda for Europe. The goal of this agenda is to cover at least 50% of the EU with a connection speed of over 100 Mbit/S and to reach full coverage with a minimum speed of 30 Mbit/S by 2020 (European Commission, 2014). The OECD offers data on the number of fixed-broadband subscriptions for its member nations[9] from 2009 onwards. Geographically small but highly developed nations such as Switzerland and the Netherlands show the highest degree of penetration with high-speed connections at over 40 subscriptions per 100 inhabitants. On the other end, only slightly more than one subscription per ten inhabitants exists in Turkey and Mexico. A full overview of the data is given in Appendix 7.6. Vogiatzoglou (2009) shows that ICT infrastructure (proxied by telephone landlines) impacts ICT exports positively. It is therefore likely that broadband penetration promotes ICT exports, especially for services, as they rely on highspeed connections to provide their work and improve its quality. The implications for the importer are twofold: On the one hand, comparative advantage theory predicts that an improvement of broadband penetration will adversely affect imports. On the other hand, a certain level of technological development and internet connection is necessary to 1) be able to find services from abroad and 2) be able to use foreign services that rely exclusively or mostly on online data transfers.

[8] The data can be accessed under http://ghdx.healthdata.org/record/ihme-data/global-human-capital-estimates-1990-2016

[9] The dataset can be accessed at https://stats.oecd.org/, under the ICT tab

In addition, the demand for ICT manufactures might also increase, assuming that the availability of high-speed internet leads to the creation or expansion of firms that require those goods. The effects on the importer's side are therefore unclear.

**Table 6:** Per country broadband subscriptions per 100 inhabitants

| Variable | Obs. | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| Subscriptions | 333 | 28.554 | 8.138 | 8.07 | 47.048 |

## 3.5 Gravity Model Components

The inclusion of the interaction effect affects the number of necessary variables that are otherwise highly relevant for models that aim to explain bilateral trade. This section is therefore divided into two parts. The first part describes the time-variant variables that are included in the main regression formula, which includes the country-pair interaction effect. The second part describes the non-shifting variables that are part of standard gravitational models but are absorbed by the country-pair fixed effect.

### Variables included in the Regressions with the Interaction Effect

One of the main building blocks of any Gravity Model is the income of the exporting and importing nation. Apart from its general effect on supply and demand, the assumption of economies of scale in combination with transport costs implies a comparative advantage from a large domestic market, as this means that domestic producers can produce larger amounts without having to bear the negative competitiveness effects of trade costs. The data is provided by the OECD and is denominated in US-Dollars at current exchange rates[10].

Following Vogiatzoglou (2009), the real effective exchange rate (REER) will be used as a proxy for cost competitiveness. Data for the REER is supplied by Bruegel, a European economics think tank[11]. The REER consists of two elements, the nominal effective exchange rate (NEER) and the ratio of consumer price indices, calculated as domestic/foreign. The NEER is a weighted average of a countries' currency's bilateral exchange rates (units of foreign currency per unit of domestic currency), with country weights based on bilateral trade as well as estimated competition in third-country markets (Darvas, 2012).

[10] Access under https://stats.oecd.org/index.aspx?queryid=60702
[11] REER data can be found at http://bruegel.org/publications/datasets/real-effective-exchange-rates-for-178-countries-a-new-database/

**Additional variables for OLS Regressions and Robustness Checks**

The elimination of the interaction effect will create the necessity to include proximity measures of various kinds. Standard literature on Gravity Models will include a measure of transport costs, often proxied by distance (Egger & Pfaffermayr, 2003). Although Irarrazabal et al. (2015) show that those costs have a lesser impact on the trade of goods with a high value to weight ratio, they are significant nevertheless. Distance is usually measured between capitals, although this does not necessarily reflect the actual transport cost of trade flows. An example of this would be the close proximity of the heavily industrialized Ruhr Region to France and the Benelux states, which is not reflected by the distance from Berlin to each of these nations' capitals. Therefore, this thesis will use the shortest distance between two countries in thousand kilometers as a proxy for transport costs. The values are calculated using R with the help of the "maps" and "geosphere" libraries.

**Table 7:** Gravity Model Variables Overview

| Variable | Type | Source | Exp. coefficient sign |
|---|---|---|---|
| Exporter GDP | Numeric (Float) | OECD | Positive |
| Importer GDP | Numeric (Float) | OECD | Positive |
| Exporter Real Exchange Rate | Numeric (Float) | Bruegel | Negative |
| Importer Real Exchange Rate | Numeric (Float) | Bruegel | Positive |
| Distance | Numeric (Float) | R calculation | Negative |
| Water Access | Binary | Manual | Positive |
| Shared Language | Binary Interaction | Manual | Positive |
| EU | Binary Interaction | Manual | Positive |
| Eurozone | Binary Interaction | Manual | Positive |

In addition, cultural proximity is proxied by shared language, as the often-used common border dummy is already captured by the closest distance variable. All OECD member states are WTO members and therefore subject to the General Agreement on Tariffs and Trade, however the European Economic Union presents a special case due to its regulatory and monetary convergence. Since all EU member nations investigated in this thesis have been members during the entire observation period, this dummy for both-sided EU membership is only needed for the regressions without country-pair fixed effects. Eurozone membership, on the other hand, varies for the Baltic States over the observed period and is therefore included in all regressions. The variables described in this section will be displayed in the regression tables under *Gravity Model Variables*.

### 3.6 Country and Time Selection

The OECD offers data on most of the variables required for this study for almost all of its member states. For the dependent variables, the consistency of methods between the calculation of service exports and manufacturing exports allows for a similar interpretation. While many emerging nations, such as China and India, are rapidly gaining ground in ICT trade, they do not yet publicly offer consistent and reliable data on all of the required variables. Therefore, in light of the rich data on OECD economies, they will be analyzed for this thesis. This means that for the analysis of manufactures all OECD member states can be examined. The service dataset does not provide export data for Finland, Mexico, Norway, Spain, Turkey and the United Kingdom, thereby reducing the number of examined states to 30.

## 4 Empirical Results

This section describes the results of the empirical application of the model developed in chapters 2 and 3.

### 4.1 ICT Services

Table 8 reports the coefficient estimates for the regression of total ICT service exports. The first three estimate columns represent the coefficients for the pooled OLS regression, while the latter three columns show the results of the fixed-effects regressions. The coefficients of the full regression specification discussed in chapter 3.2 are found in column FE(6). In accordance with the results of Psychoyios & Dotsis (2018), R&D Intensity has the expected significant positive effect: An increase of the positive difference in R&D Intensity between the exporting and importing nation by one percentage point yields an approximate c.p. increase of ICT service exports by 17 percent.

Relative endowment with human capital does not impact exports in a clear direction: An increase of the positive difference of average years of schooling by one year is c.p. linked with an approximate 14 percent increase in ICT service exports, although the effect is not even marginally significant. R&D Spillover, on the other hand, has a negative effect on ICT Service exports. An increase in the positive difference of the average R&D Spillover by one p.p. is linked with an approximate 8 percent reduction in exports. An explanation for this might be that the positive productivity effects of spillovers, which are also shown in empirical examinations (see Coe & Helpman, 1995 or Engelbrecht, 1997), are overshadowed by the competition of the countries from where the spillover effects originate. Since the estimated coefficient of distance is negative and highly significant in the OLS regression (not included in the result table), having a high R&D Spillover value implies that neighboring countries are also investing strongly in R&D. Another possibility is the lock-in effect described by Fagerberg (1996), in which spillovers have a limited reach and only affect the firms of the country of origin.

**Table 8:** Aggregated ICT Service Estimates

| Dependent variable: Log Exports | OLS(1) | OLS(2) | OLS(3) | FE(4) | FE(5) | FE(6) |
|---|---|---|---|---|---|---|
| R&D Intensity Difference | 0.189$^{***}$ | 0.162$^{***}$ | 0.245$^{***}$ | 0.183$^{***}$ | 0.171$^{***}$ | 0.174$^{***}$ |
| | (0.031) | (0.024) | (0.021) | (0.039) | (0.039) | (0.039) |
| R&D Spillover Difference | 0.153$^{**}$ | 0.473$^{***}$ | -0.025 | -0.111$^{*}$ | -0.102$^{*}$ | -0.083$^{*}$ |
| | (0.075) | (0.057) | (0.050) | (0.060) | (0.060) | (0.043) |
| Human Capital Difference | -0.171$^{***}$ | -0.207$^{***}$ | -0.089$^{***}$ | 0.046 | 0.150$^{*}$ | 0.137 |
| | (0.029) | (0.024) | (0.020) | (0.076) | (0.083) | (0.084) |
| ICT Infrastructure Difference | -0.007 | -0.013$^{***}$ | -0.013$^{***}$ | -0.007 | -0.007 | -0.004 |
| | (0.005) | (0.004) | (0.003) | (0.006) | (0.006) | (0.006) |
| Log GDP Exporter | | 0.645$^{***}$ | 0.728$^{***}$ | | 0.685$^{***}$ | 0.631$^{***}$ |
| | | (0.016) | (0.014) | | (0.236) | (0.237) |
| Log GDP Importer | | 0.641$^{***}$ | 0.833$^{***}$ | | 1.093$^{***}$ | 1.057$^{***}$ |
| | | (0.017) | (0.015) | | (0.213) | (0.213) |
| REER Exporter | | | -0.020$^{***}$ | | | 0.007$^{***}$ |
| | | | (0.003) | | | (0.002) |
| REER Importer | | | 0.006$^{**}$ | | | 0.004$^{**}$ |
| | | | (0.002) | | | (0.002) |
| Gravity Model Variables | | | All | | | Euro Area |
| $N$ | 4924 | 4924 | 4924 | 4924 | 4924 | 4924 |
| adj. $R^2$ | 0.018 | 0.467 | 0.615 | 0.942 | 0.943 | 0.943 |

Standard errors in parentheses
$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

This effect leads to a situation in which global technology leaders further specialize in high-tech exports, without having spillover effects of their technological progress enhance the catching-up process of other nations. Contrary to Vogiatzoglou's (2009) results, the coefficient for ICT infrastructure neither has the expected sign nor is it significant. Although Vogiatzoglou's results show a small positive effect, albeit on ICT manufacturing, there are possible explanations for this result. First, as discussed in chapter 3, the demand effects of high-speed internet may be stronger than the comparative advantage or productivity-enhancing effects. This means that good coverage with high-speed connections allows firms to make use of foreign services instead of opting for domestic solutions. If those service-demanding firms are more spread out throughout the country than the service-supplying firms, wide coverage with high-speed internet is more important for the importing nation when assuming an even distribution. In addition to that, the high-costs that are associated with the expansion of fiberglass networks may prohibit ICT firms, especially those from the telecommunication industry, from investing in other areas that positively affect ICT service exports, such as artificial intelligence. This theory is supported by the more significant and more negative coefficient in the regression for Telecommunication Services (see appendix).

As suggested by standard Gravity theory, the size of both nations has an economically and statistically significant positive effect on exports. The coefficient for the exporter REER, on the other hand, is not in line with theoretical predictions on cost competitiveness, but the effect is small. Vogiatzoglou (2009) estimated a small but significant negative effect of an increase of the REER, but the dependent variable of his regressions is export specialization instead of bilateral exports.

## 4.2 ICT Manufacturing

Table 9 presents coefficient estimates for exports of ICT goods. As for ICT services, the first three estimate columns present pooled OLS estimates, while columns 4 to 6 show the results for the fixed-effects regressions. Again, the main regression of interest is FE(6). One finding that stands in contrast to the estimates by Vogiatzoglou (2009) is the insignificance of the R&D coefficient. On the other side, this result is more in line with the estimates for the European Union by Psychoyios & Dotsis (2018) and the results for the best matching industries investigated by Wakelin (1998). The difference in the analyzed period might also have caused the observed variability in results. While Psychoyios & Dotsis and Vogiatzoglou analyzed datasets from the early 2000s, this dataset focuses on data from 2009-2017. Hence, it is possible that production is standardized to some extent and that R&D is geographically decoupled from production due to further globalization and outsourcing. Similar to ICT Services, the coefficient of

Spillover is negative and significant: A one percentage point increase in the difference of import-weighted R&D Spillover c.p. is linked to an approximate reduction of ICT Manufacturing Exports by 24 percent. Again, the arguments in the previous section can apply and this may be caused by the competition effect being stronger than the positive productivity effect of spillovers. The coefficient of Human Capital is similar to that in the previous section, but it is significant at the 10% level in this regression. According to the results of the regression, a one-year increase in the positive difference in average schooling c.p. increases exports by approximately 12 percent.

**Table 9:** Total ICT Manufacturing Exports Estimates

| Dependent variable: Log Exports | OLS(1) | OLS(2) | OLS(3) | FE(4) | FE(5) | FE(6) |
|---|---|---|---|---|---|---|
| R&D Intensity Difference | 0.187*** | 0.150*** | 0.145*** | 0.043 | 0.043 | 0.042 |
| | (0.026) | (0.021) | (0.018) | (0.037) | (0.036) | (0.036) |
| R&D Spillover Difference | 0.101 | 0.094* | 0.095** | -0.207*** | -0.246*** | -0.243*** |
| | (0.065) | (0.052) | (0.043) | (0.061) | (0.062) | (0.062) |
| Human Capital Difference | -0.034 | 0.051** | 0.047*** | 0.045 | 0.117* | 0.121* |
| | (0.023) | (0.021) | (0.017) | (0.058) | (0.064) | (0.065) |
| ICT Infrastructure Difference | 0.006 | -0.002 | 0.001 | 0.033*** | 0.027*** | 0.027*** |
| | (0.004) | (0.004) | (0.003) | (0.005) | (0.006) | (0.006) |
| Log GDP Exporter | | 0.852*** | 1.030*** | | 0.851*** | 0.800*** |
| | | (0.016) | (0.014) | | (0.203) | (0.204) |
| Log GDP Importer | | 0.687*** | 0.866*** | | 1.682*** | 1.641*** |
| | | (0.016) | (0.014) | | (0.203) | (0.204) |
| REER Exporter | | | 0.017*** | | | 0.005*** |
| | | | (0.002) | | | (0.002) |
| REER Importer | | | 0.009*** | | | 0.004** |
| | | | (0.002) | | | (0.002) |
| Gravity Model Variables | | | All | | | Euro Zone |
| $N$ | 10003 | 10003 | 10003 | 10003 | 10003 | 10003 |
| adj. $R^2$ | 0.011 | 0.351 | 0.589 | 0.910 | 0.911 | 0.911 |

Standard errors in parentheses
$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Contrary to the estimates for ICT services, the difference in ICT infrastructure has a positive effect on exports. An increase in the positive difference in broadband subscriptions by one subscription is c.p. linked with an approximate 3% increase in exports. This may be because points brought forward in the last section concerning the positive demand effects of ICT infrastructure are not as important for manufactured goods, so that the positive technology diffusion effects of better infrastructure prevail. In addition, research suggests positive productivity effects of ICT usage (see Dahl et al., 2011 and Pilat & Lee, 2001). Following the New Trade Theory with firm heterogeneity, an increase in productivity may allow more firms to stem the fixed costs of exporting and may thereby increase exports through an increase of the extensive margin. As in the previous regressions, GDP and REER of both exporter and importer have a significant and positive effect on exports.

## 4.3 Fixed vs. Random Effects

In chapter 3.1, several arguments were discussed on why a fixed-effects model is most likely to be the better specification for the analyzed model. This empirical assumption is supported by the Hausman tests, which were performed using standard stata functionality. For ICT manufacturing and ICT services, the null hypothesis that random-effects estimators are appropriate and consistent can be rejected.

**Table 10**: Hausman Test Results

| Hausman (1975) specification test for ICT services | | Hausman (1975) specification test for ICT manufacturing | |
|---|---|---|---|
| Chi-square test value | 143.808 | Chi-square test value | 165.218 |
| P-value | 0 | P-value | 0 |

## 4.4 Discussion

While the findings are generally congruent with previous empirical studies, some important differences emerged. Although they may simply be due to the variation in time periods that are covered by the datasets or due to the richer dataset with bilateral data, they need to be discussed nonetheless. One of the most important differences compared to the previous studies on ICT exports is the lack of significance of the R&D coefficient for exports of ICT manufacturing. While the argument brought forward in 4.2 can be the cause, other factors might have affected this result. A look at the subdivided regressions in appendix 7.8 reveals that the coefficient estimates of R&D are negative and significant for consumption goods, negative and insignificant for capital goods but positive and significant for intermediate goods. A potential cause of this could be that firms that process these intermediate goods into final goods are less dependent on research and development, which therefore affects their cost competitiveness negatively compared to the firms producing the intermediate inputs in the first place. This point is made by Dai et al. (2016), although only for the case of China, which is not part of this dataset. Additionally, the authors explain that Chinese processing firms enjoy a very supportive legal and fiscal environment, which is not the case for processing firms from those nations that are examined in this thesis. For the specific case of the EU, Psychoyios & Dotsis (2018) also estimate a negative impact of R&D expenses on exports, which they attribute to the inability of European firms to translate R&D into innovative and competitive products on a short-term basis. Another difference in results compared to the previous studies is the positive sign of the coefficient of the exporter's REER. This stands in contrast to the findings of Vogiatzoglou and theoretical predictions of cost competitiveness. It is possible that price elasticity of demand for high-technological goods such as the ones studied in this thesis is relatively low and that customer loyalty is high, so that an increase of the REER of an important provider of such goods, such as the Eurozone, can lead to this result.

# 5 Robustness Tests

## 5.1 Variable exclusion

The following two tables, Table 11 and Table 12, report the results of robustness checks performed in Stata. These tests were performed using the *checkrob* function programmed by Barslund (2007). This function distinguishes between core variables, which are always included in the regressions, and tested variables, which are omitted and included in all possible combinations. The core variables in this thesis are Gravity theory and cost competitiveness components of the bilateral trade model, while the tested variables are the main variables of interest for the model of bilateral ICT exports. Since the program does not support fixed-effects estimations, the regression used for the test shown in Table 11 is built on the regression named *OLS(3)* from chapter 4.1, which includes all the components of the Gravity Model used in the OLS regressions. The signs, magnitudes and significances for the for the first four variables reflect those of regression *OLS(3)*, with the sole exception of the exporter REER, which has the same significance but a negative coefficient, which is more in line with theoretical predictions on cost competitiveness. The additional variables, which are subsumed under *Gravity Model Variables* in the regular regression tables, are highly significant and have the expected sign, with the exception of the Euro Zone dummy. Similar results can be observed for the tested variables, as the signs and significances are all congruent with those of regression *OLS(3)*. This leads to the conclusion that the core and tested variable parts of the model are robust to changes in the composition of the tested variables.

**Table 11:** Robustness Check Results: Total ICT Services

| Core Variables | Max. | Min. | Mean | S.D. | % Significance Level |
|---|---|---|---|---|---|
| Log GDP Exporter | 0,786 | 0,719 | 0,756 | 0,014 | 1 |
| Log GDP Importer | 0,845 | 0,776 | 0,806 | 0,015 | 1 |
| REER Exporter | -0,011 | -0,02 | -0,015 | 0,003 | 1 |
| REER Importer | 0,007 | 0,002 | 0,005 | 0,002 | 5 |
| Distance/1000 | -0,144 | -0,154 | -0,149 | 0,009 | 1 |
| EU | 1,273 | 1,174 | 1,208 | 0,072 | 1 |
| Euro Zone | 0,077 | 0,043 | 0,055 | 0,053 | 0 |
| Shared Language | 1,502 | 1,436 | 1,467 | 0,109 | 1 |
| Tested Variables | Max. | Min. | Mean | S.D. | |
| R&D Intensity Difference | 0,245 | 0,146 | 0,21 | 0,019 | 1 |
| Spillover Difference | 0,163 | -0,053 | 0,06 | 0,049 | 0 |
| Human Capital Difference | -0,059 | -0,137 | -0,093 | 0,018 | 1 |
| Infrastructure Difference | 0,004 | -0,022 | -0,009 | 0,003 | 1 |

Table 12 displays the results of *checkrob* test results for ICT Manufacturing Exports. The base regression is *OLS(3)* from Table 9. A look at the core variable test results shows that the significance for the Euro Zone dummy and the REER Importer coefficient is enhanced. The signs on the coefficients of the tested variables are congruent to those of regression *OLS(3)*, but the spillover and infrastructure coefficients are more significant, which suggests interdependencies between the variables that come to light when variables are systematically omitted.

## 5.2 Absolute R&D Values

So far, all the measures used in this thesis, with exception of the “standard” Gravity Theory measures, were calculated relative to the countries’ size or in the case of spillovers, relative to the size of all trade partners. However, it is possible that the success of research and development is more dependent on the absolute value of funding, rather than on how intensively a nations’ income is used for R&D. For this robustness check, the difference in natural logs of total R&D expenditure is used as an independent variable.

**Table 12:** Robustness Checks: Total ICT Manufactures

| Core Variables | Max. | Min. | Mean | S.D. | % Significance Level |
|---|---|---|---|---|---|
| Log GDP Exporter | 1,075 | 1,015 | 1,038 | 0,013 | 1 |
| Log GDP Importer | 0,881 | 0,821 | 0,857 | 0,013 | 1 |
| REER Exporter | 0,02 | 0,015 | 0,017 | 0,002 | 1 |
| REER Importer | 0,01 | 0,005 | 0,008 | 0,002 | 1 |
| Distance/1000 | -0,233 | -0,235 | -0,234 | 0,006 | 1 |
| EU | 1,441 | 1,437 | 1,438 | 0,06 | 1 |
| Euro Zone | -0,316 | -0,316 | -0,316 | 0,054 | 1 |
| Shared Language | 0,852 | 0,852 | 0,852 | 0,107 | 1 |
| Tested Variables | Max. | Min. | Mean | S.D. | |
| R&D Intensity Difference | 0,191 | 0,145 | 0,162 | 0,016 | 1 |
| Spillover Difference | 0,244 | 0,071 | 0,155 | 0,041 | 1 |
| Human Capital Difference | 0,109 | 0,045 | 0,065 | 0,014 | 1 |
| Infrastructure Difference | 0,018 | 0,001 | 0,009 | 0,002 | 5 |

Comparing the results of regression *FE(6)* in Table 13 to those of Table 8 shows that changing the variable does not yield significantly different results. A one percent increase of the positive difference in absolute R&D expenses is linked c.p. to an approximate 0.3 percent increase in export volume. The coefficient on R&D spillover is also unchanged in sign and significance and only slightly altered in magnitude. Here, a one percent increase of the positive difference in absolute R&D spillover values is linked c.p. to an approximate 0.07 percent decrease in export volume One difference that can be seen is the drop of significance of the log GDP of the exporting country, which is understandable given that the absolute R&D values are formed using GDP. The results for ICT manufactures, which can be viewed in appendix 7.9, show no difference in coefficient signs or significances compared to the results in Table 9.

## 5.3 Dropping the Interaction Effect

As discussed in section 3.1, Egger & Pfaffermayr (2003) argue that the optimal estimation of a Gravity Model with panel data should include an importer-exporter interaction dummy. So far, this dummy has been used for all the regressions in this thesis. The interaction is left out in the following regression, only leaving the exporter, importer and year fixed effects. By dropping the interaction effect, the intricacies of the trade relationship between two countries are only accounted for by the included control dummies of the Gravity Model.

**Table 13:** Absolute R&D Values Estimates for ICT Services

| Dependent variable: Log Exports | OLS(1) | OLS(2) | OLS(3) | FE(4) | FE(5) | FE(6) |
|---|---|---|---|---|---|---|
| Log Total R&D Difference | 0.085*** | 0.175*** | 0.429*** | 0.233*** | 0.259*** | 0.267*** |
| | (0.014) | (0.045) | (0.038) | (0.064) | (0.064) | (0.064) |
| R&D Spillover Difference | 0.238*** | 0.523*** | 0.005 | -0.077 | -0.088 | -0.066* |
| | (0.073) | (0.057) | (0.050) | (0.059) | (0.060) | (0.034) |
| Human Capital Difference | -0.111*** | -0.213*** | -0.105*** | 0.001 | 0.137 | 0.127 |
| | (0.031) | (0.024) | (0.020) | (0.078) | (0.083) | (0.085) |
| ICT Infrastructure Difference | -0.008 | -0.010** | -0.015*** | -0.004 | -0.006 | -0.004 |
| | (0.005) | (0.004) | (0.003) | (0.006) | (0.006) | (0.006) |
| Log GDP Exporter | | 0.476*** | 0.296*** | | 0.464* | 0.400* |
| | | (0.052) | (0.044) | | (0.238) | (0.238) |
| Log GDP Importer | | 0.810*** | 1.270*** | | 1.299*** | 1.270*** |
| | | (0.052) | (0.045) | | (0.215) | (0.214) |
| REER Exporter | | | -0.017*** | | | 0.008*** |
| | | | (0.003) | | | (0.002) |
| REER Importer | | | 0.005** | | | 0.004** |
| | | | (0.002) | | | (0.002) |
| Gravity Model Variables | | | All | | | Euro Zone |
| *N* | 4924 | 4924 | 4924 | 4924 | 4924 | 4924 |
| adj. $R^2$ | 0.018 | 0.436 | 0.614 | 0.942 | 0.943 | 0.943 |

This change has a strong effect on the coefficient estimates: As can be seen from Table 14, ICT service trade is now almost exclusively explained by the components of standard gravitational models. Contrasting to theoretical predictions of the Gravity Model, exporter GDP does not play a role in this, while the variables for cultural and economic proximity are statistically and economically significant. Out of the main variables of interest, the coefficient signs remain the same, but solely R&D has a significant effect on exports, albeit only at the 10%-level. Given the intangible nature of ICT Service trade, it is unlikely that all bilateral effects can be absorbed using dummy variables, which arguably makes the expanded model the preferred choice. The results for the manufacturing sector are displayed in Table 15. Compared to ICT services, the results for manufactures are a lot closer to those with fixed effects for country pairs, which implies that the trade in tangible ICT goods is less affected by the unobservable factors that connect the markets of two nations.

**Table 14:** Regression without pair fixed-effect, ICT Services

| Dependent variable: Log Exports | Coef. | Std.Err. | Sig. |
|---|---|---|---|
| R&D Difference | 0.134 | 0.073 | * |
| Spillover Difference | -0.111 | 0.115 | |
| Human Capital Difference | 0.122 | 0.156 | |
| Infrastructure Difference | -0.002 | 0.011 | |
| Log GDP Exporter | 0.200 | 0.438 | |
| Log GDP Importer | 1.043 | 0.399 | *** |
| REER Exporter | 0.008 | 0.004 | * |
| REER Importer | 0.005 | 0.003 | |
| EU Membership | 0.918 | 0.127 | *** |
| Euro Zone | 0.029 | 0.058 | |
| Distance/1000 | -0.020 | 0.001 | *** |
| Water Access Exporter | 1.417 | 1.217 | |
| Water Access Importer | 0.743 | 1.108 | |
| Shared Language | 0.767 | 0.094 | *** |
| R-squared | 0.794 | Number of obs. | 4919 |

**** p<0.01, ** p<0.05, * p<0.1*

# 6 Conclusion

This thesis aimed to expand on previous literature on international competitiveness in the ICT industry by weaving key competitiveness variables into a bilateral trade model. Two strands of literature were mainly used in the regression model presented in this thesis. The first strand focused on the determinants of competitiveness, mainly through the enhancement of innovation. The discussed papers yielded the four main variables that enhance innovation, productivity and technology diffusion: R&D intensity, R&D spillover, human capital and ICT infrastructure. The second strand was concerned with the proper method of modeling the intensity of trade between two nations. These papers led to the development of a slightly augmented bilateral trade model in which the four main explanatory variables were embedded and exports were modeled as a result of differences in the main variables. The results of the regressions performed in this thesis differ by sector and are partially congruent with the results of previous empirical works. For ICT service exports, R&D intensity is a significant positive determinant, as can be expected from a highly innovative field and as shown by previous empirical works presented in section 2.1. R&D spillovers, on the other hand, have a highly significant negative impact on exports, while ICT infrastructure and human capital have no significant effect.

**Table 15**: Regression without pair fixed-effect, ICT Manufactures

| Dependent variable: Log Exports | Coef. | Std.Err. | Sig. |
|---|---|---|---|
| R&D Difference | 0.036 | 0.053 | |
| Spillover Difference | -0.260 | 0.091 | *** |
| Human Capital Difference | 0.124 | 0.095 | |
| Infrastructure Difference | 0.027 | 0.008 | *** |
| Log GDP Exporter | 0.793 | 0.299 | *** |
| Log GDP Importer | 1.618 | 0.297 | *** |
| REER Exporter | 0.005 | 0.003 | * |
| REER Importer | 0.004 | 0.003 | |
| EU Membership | 0.715 | 0.079 | *** |
| Euro Zone | 0.375 | 0.051 | *** |
| Distance/1000 | 0.000 | 0.000 | *** |
| Water Access Exporter | -1.709 | 0.839 | ** |
| Water Access Importer | -1.348 | 0.833 | |
| Shared Language | 1.155 | 0.080 | *** |
| R-squared | 0.794 | Number of obs. | 4919 |

**** p<0.01, ** p<0.05, * p<0.1*

The results differ for ICT manufacture exports, where human capital and ICT infrastructure are the key positive determinants of exports, while R&D spillovers remain a significant negative factor. R&D intensity has no significant effect on manufacture exports, possibly hinting at an inability to transform research into viable technologies, as assumed by Psychoyios & Dotsis (2018) for the European Union. The results were subjected to three robustness checks, out of which only the removal of the country-pair fixed effect had a significant impact on the coefficient estimates for ICT services. While the variables that belong to the Gravity Model part of the regression specification remained significant, the estimates for the main explanatory variables, except for R&D difference, became insignificant.

This thesis is subject to a set of limitations. One limitation is the lack of a comprehensive international firm-level data set. The identification of competitiveness factors on a micro-scale is potentially more valuable to policymakers and firms. A second important limitation is the inability to access reliable and comparable data on some key emerging markets. Out of these markets, China and India are of the largest importance, as they account for a large and increasing share of global ICT Manufacturing and Service exports respectively. Between 2008 and 2015, China's exports of ICT products grew by 49 percent. Although OECD countries still account for the vast majority of ICT exports, further research into the factors that allow for the strong growth of these emerging markets' ICT markets might yield interesting conclusions for international competitiveness and growth potential.

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# 7 Appendix

## 7.1 Country List ICT Services

2009-2017

Australia

United States

2010-2017

| | |
|---|---|
| Austria | Italy |
| Belgium | Japan |
| Canada | Korea |
| Chile | Latvia |
| Czech Republic | Lithuania |
| Denmark | Luxembourg |
| Estonia | Netherlands |
| France | New Zealand |
| Germany | Poland |
| Greece | Portugal |
| Hungary | Slovak Republic |
| Iceland | Slovenia |
| Ireland | Sweden |
| Israel | Switzerland |

## 7.2 Country List ICT Manufacturing

2009-2017

| | |
|---|---|
| Australia | Korea |
| Austria | Latvia |
| Belgium | Lithuania |
| Canada | Luxembourg |
| Chile | Mexico |
| Czech Republic | Netherlands |
| Denmark | New Zealand |

| | |
|---|---|
| Estonia | Norway |
| Finland | Poland |
| France | Portugal |
| Germany | Slovak Republic |
| Greece | Slovenia |
| Hungary | Spain |
| Iceland | Sweden |
| Ireland | Switzerland |
| Israel | Turkey |
| Italy | United Kingdom |
| Japan | United States |

## 7.3 R&D Intensity by Country

**Summary statistics: R&D Intensity by Country**

| Country | Obs | Mean | Std.Dev. | Min | Max |
|---|---|---|---|---|---|
| Australia | 7 | 2.168 | .21 | 1.856 | 2.407 |
| Austria | 13 | 2.689 | .307 | 2.166 | 3.087 |
| Belgium | 13 | 2.101 | .264 | 1.782 | 2.488 |
| Canada | 14 | 1.802 | .146 | 1.53 | 2.004 |
| Chile | 10 | .359 | .024 | .31 | .389 |
| Czech Republic | 13 | 1.503 | .312 | 1.146 | 1.973 |
| Denmark | 13 | 2.778 | .25 | 2.393 | 3.055 |
| Estonia | 13 | 1.428 | .431 | .852 | 2.307 |
| Finland | 13 | 3.347 | .294 | 2.746 | 3.749 |
| France | 13 | 2.163 | .093 | 2.025 | 2.276 |
| Germany | 13 | 2.692 | .199 | 2.421 | 2.939 |
| Greece | 13 | .701 | .156 | .527 | 1.007 |
| Hungary | 13 | 1.134 | .18 | .86 | 1.389 |
| Iceland | 10 | 2.385 | .366 | 1.755 | 2.922 |
| Ireland | 13 | 1.384 | .189 | 1.177 | 1.608 |
| Israel | 13 | 4.151 | .156 | 3.874 | 4.429 |
| Italy | 13 | 1.207 | .103 | 1.047 | 1.343 |
| Japan | 13 | 3.24 | .101 | 3.03 | 3.4 |
| Korea | 14 | 3.42 | .692 | 2.352 | 4.289 |

| | | | | | |
|---|---|---|---|---|---|
| Latvia | 13 | .578 | .097 | .4 | .697 |
| Lithuania | 13 | .858 | .099 | .747 | 1.041 |
| Luxembourg | 13 | 1.465 | .171 | 1.244 | 1.677 |
| Mexico | 13 | .472 | .057 | .369 | .533 |
| Netherlands | 13 | 1.841 | .137 | 1.643 | 2.032 |
| New Zealand | 6 | 1.196 | .06 | 1.12 | 1.263 |
| Norway | 13 | 1.657 | .165 | 1.456 | 2.032 |
| Poland | 13 | .74 | .173 | .551 | 1.004 |
| Portugal | 13 | 1.237 | .275 | .729 | 1.58 |
| Slovak Republic | 13 | .662 | .221 | .448 | 1.175 |
| Slovenia | 13 | 1.952 | .453 | 1.368 | 2.58 |
| Spain | 13 | 1.237 | .096 | 1.038 | 1.351 |
| Sweden | 13 | 3.323 | .111 | 3.146 | 3.5 |
| Switzerland | 4 | 2.987 | .348 | 2.673 | 3.374 |
| Turkey | 12 | .735 | .129 | .502 | .881 |
| United Kingdom | 13 | 1.636 | .048 | 1.546 | 1.691 |
| United States | 13 | 2.685 | .107 | 2.49 | 2.819 |

## 7.4 R&D Spillover by Country

**Summary statistics**

| COUNTRY | Obs | Mean | Std.Dev. | Min | Max |
|---|---|---|---|---|---|
| Australia | 5 | 2.635 | .034 | 2.588 | 2.674 |
| Austria | 11 | 2.22 | .143 | 2.01 | 2.478 |
| Belgium | 11 | 2.128 | .084 | 1.989 | 2.226 |
| Canada | 11 | 2.565 | .11 | 2.417 | 2.814 |
| Chile | 11 | 2.253 | .187 | 2.079 | 2.753 |
| Czech Republic | 11 | 2.078 | .105 | 1.926 | 2.305 |
| Denmark | 11 | 2.518 | .139 | 2.235 | 2.7 |
| Estonia | 11 | 2.114 | .276 | 1.746 | 2.457 |
| Finland | 11 | 2.509 | .115 | 2.308 | 2.65 |
| France | 11 | 2.028 | .12 | 1.855 | 2.199 |
| Germany | 11 | 1.995 | .07 | 1.9 | 2.079 |
| Greece | 11 | 2.031 | .099 | 1.895 | 2.196 |
| Hungary | 11 | 2.179 | .107 | 2.079 | 2.387 |
| Iceland | 9 | 2.429 | .164 | 2.103 | 2.582 |
| Ireland | 11 | 2.109 | .094 | 1.981 | 2.313 |
| Israel | 11 | 2.327 | .123 | 2.108 | 2.517 |

| | | | | | |
|---|---|---|---|---|---|
| Italy | 11 | 2.099 | .084 | 1.952 | 2.199 |
| Japan | 11 | 3.027 | .2 | 2.634 | 3.238 |
| Korea | 11 | 2.844 | .052 | 2.75 | 2.933 |
| Latvia | 11 | 1.667 | .116 | 1.503 | 1.924 |
| Lithuania | 11 | 1.701 | .167 | 1.46 | 2.073 |
| Luxembourg | 11 | 2.167 | .142 | 1.928 | 2.353 |
| Mexico | 10 | 2.786 | .039 | 2.697 | 2.827 |
| Netherlands | 11 | 2.237 | .125 | 2.074 | 2.412 |
| New Zealand | 6 | 2.469 | .223 | 2.157 | 2.76 |
| Norway | 11 | 2.724 | .12 | 2.486 | 2.886 |
| Poland | 11 | 2.208 | .071 | 2.094 | 2.356 |
| Portugal | 11 | 1.967 | .087 | 1.829 | 2.112 |
| Slovak Republic | 11 | 2.08 | .232 | 1.756 | 2.403 |
| Slovenia | 11 | 2.132 | .234 | 1.878 | 2.6 |
| Spain | 11 | 2.015 | .068 | 1.907 | 2.12 |
| Sweden | 11 | 2.086 | .129 | 1.877 | 2.282 |
| Switzerland | 4 | 2.177 | .069 | 2.088 | 2.238 |
| Turkey | 11 | 2.076 | .097 | 1.933 | 2.21 |
| United Kingdom | 11 | 2.101 | .104 | 1.968 | 2.221 |
| United States | 11 | 1.747 | .436 | 1.549 | 3.058 |

## 7.5 Average Schooling by Country

**Summary statistics**

| COUNTRY | Obs | Mean | Std.Dev. | Min | Max |
|---|---|---|---|---|---|
| Australia | 10 | 14.524 | .207 | 14.208 | 14.823 |
| Austria | 10 | 13.744 | .199 | 13.45 | 14.039 |
| Belgium | 10 | 15.274 | .12 | 15.089 | 15.447 |
| Canada | 10 | 15.035 | .105 | 14.874 | 15.187 |
| Chile | 10 | 12.337 | .181 | 12.063 | 12.604 |
| Czech Republic | 10 | 14.169 | .261 | 13.789 | 14.562 |
| Denmark | 10 | 15.936 | .113 | 15.767 | 16.103 |
| Estonia | 10 | 15.137 | .205 | 14.836 | 15.443 |
| Finland | 10 | 15.631 | .123 | 15.444 | 15.809 |
| France | 10 | 15.186 | .159 | 14.932 | 15.406 |
| Germany | 10 | 13.804 | .213 | 13.488 | 14.12 |
| Greece | 10 | 13.94 | .094 | 13.788 | 14.07 |
| Hungary | 10 | 13.529 | .244 | 13.173 | 13.895 |
| Iceland | 10 | 16.25 | .104 | 16.094 | 16.404 |
| Ireland | 10 | 14.38 | .166 | 14.121 | 14.616 |
| Israel | 10 | 13.663 | .104 | 13.514 | 13.823 |

| | | | | | |
|---|---|---|---|---|---|
| Italy | 10 | 13.845 | .12 | 13.663 | 14.02 |
| Japan | 10 | 14.216 | .174 | 13.966 | 14.481 |
| Korea | 10 | 14.928 | .173 | 14.656 | 15.17 |
| Latvia | 10 | 14.383 | .265 | 13.998 | 14.781 |
| Lithuania | 10 | 14.731 | .13 | 14.55 | 14.935 |
| Luxembourg | 10 | 15.112 | .195 | 14.812 | 15.392 |
| Mexico | 10 | 9.379 | .17 | 9.139 | 9.648 |
| Netherlands | 10 | 15.843 | .147 | 15.609 | 16.047 |
| New Zealand | 10 | 14.184 | .201 | 13.886 | 14.483 |
| Norway | 10 | 15.178 | .193 | 14.883 | 15.456 |
| Poland | 10 | 14.976 | .281 | 14.536 | 15.368 |
| Portugal | 10 | 12.864 | .313 | 12.368 | 13.298 |
| Slovak Republic | 10 | 14.275 | .23 | 13.944 | 14.623 |
| Slovenia | 10 | 15.103 | .305 | 14.622 | 15.526 |
| Spain | 10 | 13.37 | .083 | 13.236 | 13.485 |
| Sweden | 10 | 14.746 | .141 | 14.535 | 14.955 |
| Switzerland | 10 | 13.489 | .229 | 13.158 | 13.837 |
| Turkey | 10 | 11.538 | .816 | 10.359 | 12.774 |
| United Kingdom | 10 | 13.993 | .188 | 13.695 | 14.255 |
| United States | 10 | 13.897 | .076 | 13.811 | 14.026 |

## 7.6 Broadband Subscriptions per 100 Inhabitants

**Summary statistics**

| COUNTRY | Obs | Mean | Std.Dev. | Min | Max |
|---|---|---|---|---|---|
| Australia | 9 | 27.302 | 2.697 | 24.055 | 32.207 |
| Austria | 9 | 26.011 | 2.609 | 21.499 | 28.87 |
| Belgium | 9 | 34.326 | 3.219 | 29.028 | 38.585 |
| Canada | 9 | 34.452 | 2.468 | 30.599 | 37.931 |
| Chile | 9 | 13.194 | 2.361 | 9.775 | 16.515 |
| Czech Republic | 9 | 25.798 | 3.598 | 19.407 | 29.62 |
| Denmark | 9 | 40.211 | 2.28 | 36.597 | 43.061 |
| Estonia | 9 | 27.919 | 1.948 | 25.368 | 31.186 |
| Finland | 9 | 30.833 | 1.046 | 29.067 | 32.183 |
| France | 9 | 37.376 | 4.142 | 30.545 | 43.011 |
| Germany | 9 | 35.641 | 2.94 | 31.034 | 40.205 |
| Greece | 9 | 26.692 | 6.21 | 17.256 | 35.291 |
| Hungary | 9 | 24.582 | 3.864 | 18.76 | 30.206 |
| Iceland | 9 | 36.202 | 1.804 | 33.544 | 38.897 |

| | | | | | |
|---|---|---|---|---|---|
| Ireland | 9 | 25.509 | 2.867 | 21.188 | 29.128 |
| Israel | 9 | 25.182 | 1.314 | 23.473 | 27.557 |
| Italy | 9 | 23.517 | 2.09 | 20.278 | 27.308 |
| Japan | 9 | 28.22 | 1.96 | 24.724 | 30.953 |
| Korea | 9 | 36.964 | 2.499 | 33.097 | 40.799 |
| Latvia | 9 | 23.95 | 2.473 | 20.4 | 27.103 |
| Lithuania | 9 | 25.798 | 3.225 | 20.038 | 29.906 |
| Luxembourg | 9 | 32.828 | 2.217 | 29.185 | 35.897 |
| Mexico | 9 | 10.818 | 1.946 | 8.07 | 13.886 |
| Netherlands | 9 | 40.017 | 1.719 | 37.084 | 42.117 |
| New Zealand | 9 | 29.696 | 3.328 | 23.82 | 33.672 |
| Norway | 9 | 37.741 | 2.247 | 34.586 | 41.027 |
| OECD - Total | 9 | 26.637 | 2.501 | 22.636 | 30.182 |
| Poland | 9 | 17.461 | 1.387 | 14.453 | 18.624 |
| Portugal | 9 | 25.828 | 5.784 | 18.295 | 34.704 |
| Slovak Republic | 9 | 20.428 | 3.923 | 14.306 | 25.83 |
| Slovenia | 9 | 25.577 | 2.459 | 21.625 | 28.918 |
| Spain | 9 | 26.423 | 3.411 | 21.235 | 31.104 |
| Sweden | 9 | 33.967 | 2.507 | 31.661 | 38.442 |
| Switzerland | 9 | 42.897 | 4.121 | 35.744 | 47.048 |
| Turkey | 9 | 11.423 | 1.931 | 8.864 | 15.088 |
| United Kingdom | 9 | 35.119 | 3.454 | 29.48 | 39.424 |
| United States | 9 | 29.962 | 2.411 | 26.036 | 33.015 |

## 7.7 ICT Services Results by Sector

**Telecommunication Services Estimates**

| Dependent variable: Log Exports | OLS(1) | OLS(2) | OLS(3) | FE(4) | FE(5) | FE(6) |
|---|---|---|---|---|---|---|
| R&D Intensity Difference | 0.185*** | 0.109*** | 0.100*** | 0.073 | 0.048 | 0.049 |
| | (0.031) | (0.026) | (0.024) | (0.055) | (0.056) | (0.056) |
| R&D Spillover Difference | -0.012 | 0.455*** | -0.066 | -0.006 | -0.041 | -0.048 |
| | (0.083) | (0.068) | (0.066) | (0.084) | (0.086) | (0.087) |
| Human Capital Difference | -0.178*** | -0.105*** | -0.028 | -0.168 | -0.099 | -0.116 |
| | (0.031) | (0.028) | (0.025) | (0.105) | (0.116) | (0.119) |
| ICT Infrastructure Difference | -0.007 | -0.024*** | -0.012*** | -0.011 | -0.019** | -0.019** |
| | (0.005) | (0.004) | (0.004) | (0.008) | (0.008) | (0.008) |
| Log GDP Exporter | | 0.633*** | 0.720*** | | -0.893*** | -0.881*** |
| | | (0.017) | (0.017) | | (0.326) | (0.328) |
| Log GDP Importer | | 0.433*** | 0.579*** | | 0.241 | 0.231 |
| | | (0.019) | (0.019) | | (0.301) | (0.302) |
| REER Exporter | | 0.757*** | 0.273*** | | 0.251*** | 0.250*** |
| | | (0.063) | (0.061) | | (0.084) | (0.085) |
| REER Importer | | | 0.004 | | | -0.001 |
| | | | (0.003) | | | (0.003) |
| Gravity Model Variables | | | All | | | Euro Zone |
| *N* | 3748 | 3748 | 3748 | 3748 | 3748 | 3748 |
| adj. $R^2$ | 0.020 | 0.375 | 0.496 | 0.898 | 0.898 | 0.898 |

Standard errors in parentheses
$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

**Computer Services Estimates**

| | OLS(1) | OLS(2) | OLS(3) | FE(4) | FE(5) | FE(6) |
|---|---|---|---|---|---|---|
| R&D Intensity Difference | 0.201*** | 0.179*** | 0.273*** | 0.125** | 0.111** | 0.109** |
| | (0.033) | (0.026) | (0.025) | (0.051) | (0.051) | (0.051) |
| R&D Spillover Difference | -0.013 | 0.666*** | 0.131** | -0.091 | -0.089 | -0.055 |
| | (0.086) | (0.067) | (0.066) | (0.077) | (0.078) | (0.079) |
| Human Capital Difference | -0.152*** | -0.207*** | -0.143*** | 0.202** | 0.355*** | 0.389*** |
| | (0.032) | (0.027) | (0.024) | (0.100) | (0.109) | (0.112) |
| ICT Infrastructure Difference | -0.011** | -0.015*** | -0.008** | -0.005 | -0.004 | 0.001 |
| | (0.005) | (0.004) | (0.004) | (0.007) | (0.008) | (0.008) |
| Log GDP Exporter | | 0.670*** | 0.718*** | | 1.077*** | 0.920*** |
| | | (0.018) | (0.018) | | (0.319) | (0.321) |
| Log GDP Importer | | 0.730*** | 0.887*** | | 1.631*** | 1.623*** |
| | | (0.020) | (0.019) | | (0.271) | (0.271) |
| REER Exporter | | 0.641*** | -0.057 | | 0.050 | 0.018 |
| | | (0.065) | (0.063) | | (0.077) | (0.077) |
| REER Importer | | | -0.021*** | | | 0.011*** |
| | | | (0.003) | | | (0.003) |
| Gravity Model Variables | | | All | | | Euro Zone |
| $N$ | 4248 | 4248 | 4248 | 4248 | 4248 | 4248 |
| adj. $R^2$ | 0.016 | 0.440 | 0.551 | 0.925 | 0.926 | 0.927 |

Standard errors in parentheses
$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

**Information Services Estimates**

| Dependent variable: Log Exports | OLS(1) | OLS(2) | OLS(3) | FE(4) | FE(5) | FE(6) |
|---|---|---|---|---|---|---|
| R&D Intensity Difference | 0.389*** | 0.225*** | 0.169*** | 0.216** | 0.134 | 0.141 |
| | (0.044) | (0.036) | (0.035) | (0.094) | (0.095) | (0.095) |
| R&D Spillover Difference | -0.936*** | -0.053 | -0.131 | 0.024 | 0.017 | -0.003 |
| | (0.111) | (0.093) | (0.096) | (0.149) | (0.152) | (0.153) |
| Human Capital Difference | 0.146*** | 0.119*** | 0.140*** | -0.246 | 0.030 | -0.024 |
| | (0.044) | (0.037) | (0.035) | (0.186) | (0.200) | (0.209) |
| ICT Infrastructure Difference | -0.030*** | -0.031*** | -0.023*** | -0.011 | -0.012 | -0.014 |
| | (0.006) | (0.005) | (0.005) | (0.013) | (0.014) | (0.014) |
| Log GDP Exporter | | 0.665*** | 0.704*** | | 0.244 | 0.141 |
| | | (0.022) | (0.025) | | (0.611) | (0.616) |
| Log GDP Importer | | 0.480*** | 0.515*** | | 2.513*** | 2.530*** |
| | | (0.024) | (0.027) | | (0.472) | (0.472) |
| REER Exporter | | 0.313*** | 0.181** | | 0.166 | 0.144 |
| | | (0.080) | (0.081) | | (0.173) | (0.174) |
| REER Importer | | | 0.028*** | | | 0.003 |
| | | | (0.005) | | | (0.005) |
| Gravity Model Variables | | | All | | | Euro Zone |
| *N* | 2294 | 2294 | 2294 | 2294 | 2294 | 2294 |
| adj. $R^2$ | 0.054 | 0.420 | 0.477 | 0.863 | 0.865 | 0.865 |

Standard errors in parentheses
$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

## 7.8 ICT Manufacturing Regression Results

**ICT Intermediate Goods Estimates**

| Dependent variable: Log Exports | OLS(1) | OLS(2) | OLS(3) | FE(4) | FE(5) | FE(6) |
|---|---|---|---|---|---|---|
| R&D Intensity Difference | 0.188*** | 0.162*** | 0.158*** | 0.114*** | 0.118*** | 0.117*** |
| | (0.027) | (0.022) | (0.019) | (0.042) | (0.042) | (0.042) |
| R&D Spillover Difference | 0.090 | 0.029 | 0.017 | -0.098 | -0.104 | -0.100 |
| | (0.068) | (0.053) | (0.046) | (0.070) | (0.071) | (0.072) |
| Human Capital Difference | -0.042* | 0.031 | 0.030* | 0.093 | 0.092 | 0.097 |
| | (0.024) | (0.021) | (0.018) | (0.066) | (0.073) | (0.075) |
| ICT Infrastructure Difference | 0.028*** | 0.020*** | 0.024*** | 0.023*** | 0.024*** | 0.024*** |
| | (0.004) | (0.004) | (0.003) | (0.006) | (0.007) | (0.007) |
| Log GDP Exporter | | 0.934***<br>(0.017) | 1.126***<br>(0.015) | | 1.381***<br>(0.234) | 1.357***<br>(0.235) |
| Log GDP Importer | | 0.779***<br>(0.017) | 0.961***<br>(0.015) | | 1.262***<br>(0.234) | 1.252***<br>(0.235) |
| REER Exporter | | | 0.016***<br>(0.002) | | | 0.002<br>(0.002) |
| REER Importer | | | 0.006***<br>(0.002) | | | 0.001<br>(0.002) |
| Gravity Model Variables | | | All | | | Euro Zone |
| *N* | 9876 | 9876 | 9876 | 9876 | 9876 | 9876 |
| adj. $R^2$ | 0.025 | 0.398 | 0.578 | 0.894 | 0.895 | 0.895 |

Standard errors in parentheses
$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

**ICT Capital Goods Estimates**

| Dependent variable: Log Exports | OLS(1) | OLS(2) | OLS(3) | FE(4) | FE(5) | FE(6) |
|---|---|---|---|---|---|---|
| R&D Intensity Difference | 0.218*** | 0.181*** | 0.159*** | -0.022 | -0.024 | -0.026 |
| | (0.026) | (0.021) | (0.018) | (0.043) | (0.043) | (0.043) |
| R&D Spillover Difference | 0.125* | 0.072 | 0.096** | -0.432*** | -0.456*** | -0.449*** |
| | (0.065) | (0.052) | (0.043) | (0.072) | (0.072) | (0.073) |
| Human Capital Differences | -0.034 | 0.055*** | 0.047*** | 0.211*** | 0.258*** | 0.265*** |
| | (0.023) | (0.021) | (0.017) | (0.068) | (0.075) | (0.076) |
| ICT Infrastructure Difference | 0.017*** | 0.007** | 0.013*** | 0.018*** | 0.014** | 0.014** |
| | (0.004) | (0.004) | (0.003) | (0.006) | (0.007) | (0.007) |
| Log GDP Exporter | | 0.893*** | 1.094*** | | 1.176*** | 1.146*** |
| | | (0.016) | (0.014) | | (0.238) | (0.240) |
| Log GDP Importer | | 0.695*** | 0.877*** | | 1.750*** | 1.743*** |
| | | (0.016) | (0.014) | | (0.238) | (0.239) |
| REER Exporter | | | 0.025*** | | | 0.003 |
| | | | (0.002) | | | (0.002) |
| REER Importer | | | 0.007*** | | | 0.001 |
| | | | (0.002) | | | (0.002) |
| Gravity Model Variables | | | All | | | Euro Zone |
| *N* | 9857 | 9857 | 9857 | 9857 | 9857 | 9857 |
| adj. $R^2$ | 0.022 | 0.376 | 0.588 | 0.879 | 0.881 | 0.881 |

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

**ICT Consumption Goods Estimates**

| Dependent variable: Log Exports | OLS(1) | OLS(2) | OLS(3) | FE(4) | FE(5) | FE(6) |
|---|---|---|---|---|---|---|
| R&D Intensity Difference | -0.186*** | -0.214*** | -0.112*** | -0.202** | -0.206** | -0.199** |
| | (0.034) | (0.034) | (0.030) | (0.082) | (0.082) | (0.083) |
| R&D Spillover Difference | 0.301*** | 0.288*** | 0.155** | 0.327** | 0.213 | 0.184 |
| | (0.087) | (0.084) | (0.074) | (0.141) | (0.144) | (0.146) |
| Human Capital Difference | 0.094*** | 0.150*** | 0.205*** | 0.220* | 0.459*** | 0.421*** |
| | (0.032) | (0.034) | (0.030) | (0.120) | (0.138) | (0.141) |
| ICT Infrastructure Difference | -0.022*** | -0.031*** | -0.036*** | 0.028** | 0.013 | 0.013 |
| | (0.005) | (0.006) | (0.005) | (0.012) | (0.013) | (0.013) |
| Log GDP Exporter | | 0.455*** | 0.827*** | | -0.450 | -0.426 |
| | | (0.027) | (0.025) | | (0.464) | (0.467) |
| Log GDP Importer | | 0.269*** | 0.601*** | | 1.912*** | 1.821*** |
| | | (0.026) | (0.024) | | (0.448) | (0.451) |
| REER Exporter | | | 0.008** | | | 0.000 |
| | | | (0.004) | | | (0.004) |
| REER Importer | | | 0.022*** | | | 0.007* |
| | | | (0.003) | | | (0.004) |
| Gravity Model Variables | | | All | | | Euro Zone |
| *N* | 8212 | 8212 | 8212 | 8212 | 8212 | 8212 |
| adj. $R^2$ | 0.010 | 0.061 | 0.310 | 0.761 | 0.762 | 0.762 |

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

## 7.9 Robustness Checks

**Absolute R&D Values estimates for ICT Manufactures**

| Dependent variable: Log Exports | OLS(1) | OLS(2) | OLS(3) | FE(4) | FE(5) | FE(6) |
|---|---|---|---|---|---|---|
| R&D Intensity Difference | 0.118*** | 0.266*** | 0.287*** | 0.048 | 0.101 | 0.100 |
| | (0.013) | (0.040) | (0.033) | (0.060) | (0.061) | (0.061) |
| R&D Spillover Difference | 0.141** | 0.123** | 0.117*** | -0.205*** | -0.253*** | -0.250*** |
| | (0.062) | (0.051) | (0.042) | (0.061) | (0.062) | (0.063) |
| Human Capital Difference | 0.060** | 0.041* | 0.034** | 0.037 | 0.105 | 0.110* |
| | (0.025) | (0.021) | (0.017) | (0.061) | (0.064) | (0.066) |
| ICT Infrastructure Difference | -0.002 | -0.004 | -0.002 | 0.034*** | 0.027*** | 0.027*** |
| | (0.004) | (0.004) | (0.003) | (0.005) | (0.006) | (0.006) |
| Log GDP Exporter | | 0.583*** | 0.737*** | | 0.773*** | 0.722*** |
| | | (0.047) | (0.038) | | (0.207) | (0.208) |
| Log GDP Importer | | 0.957*** | 1.160*** | | 1.760*** | 1.719*** |
| | | (0.047) | (0.038) | | (0.207) | (0.208) |
| REER Exporter | | | 0.017*** | | | 0.005*** |
| | | | (0.002) | | | (0.002) |
| REER Importer | | | 0.008*** | | | 0.004** |
| | | | (0.002) | | | (0.002) |
| Gravity Model Variables | | | All | | | Euro Zone |
| *N* | 10032 | 10003 | 10003 | 10032 | 10003 | 10003 |
| adj. $R^2$ | 0.013 | 0.351 | 0.590 | 0.910 | 0.911 | 0.911 |

Standard errors in parentheses
$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$