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THE RELATIONSHIP BETWEEN R&D CAPITAL, SPILLOVER EFFECTS AND LABOR PRODUCTIVITY

Yüksek Lisans Tezi

CEMİL FARUK DURMAZ

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TEZ ONAY BELGESİ

İKTİSAT (İNGİLİZCE) Anabilim Dalı İKTİSAT (İNGİLİZCE) Bilim Dalı TEZLİ YÜKSEK LİSANS öğrencisi Cemil Faruk Durmaz'nın THE RELATIONSHIP BETWEEN R&D CAPITAL, SPILLOVER EFFECTS AND LABOR PRODUCTIVITY adlı tez çalışması, Enstitümüz Yönetim Kurulunun 18.05.2016 tarih ve 2016-18/39 sayılı kararıyla oluşturulan jüri tarafından oy birliği / ~~oy çokluğu~~ ile Yüksek Lisans Tezi olarak kabul edilmiştir.

Tez Savunma Tarihi 25/05/2016

Öğretim Üyesi Adı Soyadı **İmzası**

1.	Tez Danışmanı	Yrd. Doç. Dr. MUSTAFA NEDİM SÜALP	
2.	Jüri Üyesi	Yrd. Doç. Dr. YASEMİN ÖZERKEK	
3.	Jüri Üyesi	Yrd. Doç. Dr. MUSTAFA ÇAKIR	

This Thesis is dedicated to my dearest parents and the memory of my aunt.

ACKNOWLEDGEMENTS

First and foremost, I would like to sincerely thank my supervisor, Assistant Professor M. Nedim Süalp, for his guidance and support throughout this study.

I would also like to thank my thesis committee members, Assistant Professor Yasemin Özerkek, for her many valuable advices and Assistant Professor Mustafa Çakır, for his suggestions.

Name Surname: Cemil Faruk DURMAZ

Department: Economics

Program: Economics

Supervisor: Asst. Prof. Dr. M. Nedim Sualp

ABSTRACT

THE RELATIONSHIP BETWEEN R&D CAPITAL, SPILLOVER EFFECTS AND LABOR PRODUCTIVITY

Spillover effects through capital goods imports and the effect of domestic R&D capital stock on labor productivity is empirically investigated in this thesis for 23 countries between 2002 and 2011. Results of panel data analysis indicated that technology transfer is significant and positive for a large sample. Externalities also exist between G7 economies. However, capital goods imports do not cause a knowledge transfer from G7 economies to countries with relatively and significantly lower level of productivity. The thesis contributed the literature by using labor productivity instead of total factor productivity in order to investigate the effects of externalities in samples with different set of countries.

Adı ve Soyadı: Cemil Faruk DURMAZ

Ana Bilim Dalı: İngilizce İktisat

Bölüm: İngilizce İktsat

Danışman: Yrd. Doç. Dr. M. Nedim Sualp

ÖZET

ARGE SERMAYESİ, YAYILMA ETKİSİ VE EMEK VERİMLİLİĞİ ARASINDAKİ İLİŞKİ

Bu tezde sermaye malları ithalatı yoluyla yayılma etkisi ve yurt içi ARGE sermayesinin emek verimliliği üzerindeki etkisi 2002 – 2011 yılları arasında 23 ülke için ampirik olarak incelenmiştir. Panel veri analizinin sonuçları büyük bir örneklem için teknoloji transferinin anlamlı ve olumlu olduğunu göstermiştir. Dışsallığın, G7 ülkelerinin arasında var olduğu ayrıca kanıtlanmıştır. Ancak sermaye malları ithalatı yoluyla oluşan teknoloji transferi G7 ekonomilerinden önemli ölçüde daha düşük emek verimliliği olan ülkelere doğru anlamlı bir etki oluşturmamaktadır. Bu tez, toplam faktör verimliliği yerine emek verimliliğini farklı ülke gruplarında dışsallığın etkisini ölçmekte kullanarak literature katkıda bulunmuştur.

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LIST OF ABBREVATIONS

TFP: Total Factor Productivity

GDP: Gross Domestic Product

R&D: Research and Development

FDI: Foreign Direct Investment

VIF: Variance Inflation Factor

LP: Labor Productivity

BRD: Domestic R&D Capital Stock

FRD: Foreign R&D Capital Stock

CAP: Physical Capital Stock

EMP: Total Employment

1 INTRODUCTION

Economic growth is one of the most important notions in the field of economics. Level of production in an economy is the main source of growth and the factors which are affecting the production are the determinants of it. It is a well-known fact that there are two major elements in the production process; labor and capital. Gross domestic product (GDP) of countries is generally used to measure economic growth. However, changes in the amount of labor and capital explain only some of the variations in GDP. There is an unexplained friction which is called “Solow Residual” in the neo-classical growth theory. It is plausible to say that this variation in production is actually the total factor productivity (TFP). Technological advancement is accepted as an explanation for TFP.

Endogenous growth theories focused on explaining the role of technology. Even though there is no direct measurement for TFP research and development (R&D) and human capital are the main determinants of it. Education is the proxy variable for human capital. As the education level and the number of educated people increase in a country, learning new technologies, number of innovations and inventions also rise. R&D efforts in an economy are also crucial for the technological improvement. Paul Romer is one of the pioneers in the literature for endogenous growth theories. He argued that if the Solow Residual is considered as an endogenous part of the production function, economic growth may exhibit increasing returns to scale properties. He mainly focused on the role of human capital. Aghion and Howitt also focused on the role of human capital in this theory. On the other hand, Grossman and Helpman focused on modelling R&D market and they embraced the “quality ladder” approach which provides a more realistic understanding of innovation economics. R&D expenditures of both private and government sector are investigated in the literature. It is determined that effect of private sector efforts is more significant. Although Human and knowledge capital are measured with different proxies their interaction is also vital. It is argued that their collaboration is also significant for the TFP growth. Human capital should reach and use the accumulated knowledge to become more innovative.

Definition and the boundaries of technology shed light on new and various types of research. Technical knowledge cannot be categorized considering its excludability and rivalry. In a more globalized world, either the knowledge capital embedded in high technological products or the information around the world can be excluded easily. This is why technology is considered as partially excludable. The argument on this issue leads to another notion which is called externality. Since new information produced in any industry or country can be obtained by the others, these innovations may create spillover effects throughout whole economy. The spillover effects are measured several times in the empirical literature. Imports and foreign direct investment (FDI) are the most common channels for technology transfer. Firms share information with each other via mergers and acquisitions. Countries receive new information by imports of capital goods.

This research is explaining several notions regarding endogenous growth empirically. Theoretical model of Grossman and Helpman (1991) is presented as a base for the research because the empirical study focuses on the effects of knowledge capital on productivity. Labor productivity is chosen as a dependent variable rather than TFP. Private sector R&D capital stock is chosen as the first independent variable in order to show the domestic research and development efforts of countries. Foreign R&D capital stock is also constructed to capture the spillover effects between countries via capital goods imports. Finally, impact of physical capital is also measured. Four different samples are investigated. First one consists of 24 economies between 2002 and 2011. Second sample is created by only G7 countries in the same time period. G7 countries are excluded in the third sample and unilateral technology transfer from G7 economies to countries with low labor productivity is investigated in the fourth sample.

Results proved that both internal and foreign R&D capital stock affect labor productivity positively. Countries' domestic efforts are more effective. Technology transfer is more effective in the sample of G7. It is plausible to say that labor becomes more productive using the knowledge capital they acquire. Outcome verifies the theory in more than one cases. Firstly, it is shown that knowledge capital has a significant and positive impact on the efficiency of labor. Second, externalities exist between countries.

This thesis is composed as follows; in the first section a survey of empirical and theoretical literature is explained. In section two, theoretical model is presented. Data, methodology and descriptive statistics are presented in third and fourth sections. Empirical model and analysis are stated in section five and six. Empirical Model is in section six and final remarks are in section seven.

2 LITERATURE REVIEW

2.1 Empirical Literature

In Coe and Helpman (1995), R&D efforts of a country considered as the main determinant of productivity growth. Not just only an economy's own efforts but also foreign R&D investigated as a source for country's technological progress. This point of view leads to two different sources for innovation; domestic and foreign R&D capital stock. The dichotomy brings another notion called spillover effect. Technology spillovers suggest technology transfer through different channels. This means that a country's productivity growth may be affected by another country's R&D efforts through globalization. Coe and Helpman (1995), investigates international trade as a channel of transfer. They suggested that there are both indirect and direct benefits of foreign R&D. Learning about innovations, production processes could directly boosts a country's technological progress when technology transfer through imports of goods and services do the same indirectly. In their theory, a function is derived which considers total factor productivity as a dependent variable. It should be noted that total factor productivity (TFP) is the term used to explain the factors affecting economic growth other than capital and labor which is technological progress. TFP is defined as $F= Y/K^{\beta}L^{1-\beta}$. It can be also written as $\log Y - \beta \log K + (1- \beta)\log L$. In the model labor is employed either in R&D or in manufacturing sector. Domestic R&D is simply calculated as the business sector expenditure on R&D. However there are different views on the demonstration of foreign R&D and international trade. Since models Coe and Helpman et al. investigates technology transfer trough trade, how to breakdown type of imports is a matter of discussion. There are three major approaches to this matter. Intermediate goods, capital goods or all goods and services imports can be considered as a parameter. In Coe and Helpman (1995), two extreme cases are considered. In the first one, a country's R&D efforts are originated from domestic capabilities only and in the second one, it is based on only foreign countries' R&D resources. Foreign R&D capital stock is calculated in two steps. First, by summing up the domestic R&D capital stocks of each countries' trading partners. Second one is calculating the bilateral imports share weighted foreign R&D capital stocks. An equation for the second calculation is given in Coe and Helpman (2008). In the ultimate equation they have calculated the constant and coefficients are allowed to vary between countries to capture country specific variations.

It should be noted that Coe and Helpman constructed a panel data analysis for 22 OECD countries between 1971 and 1990. A cointegration analysis is conducted to exploit the long run relationship between variables. Unit root test shows that variables are non-stationary in the paper. Cointegration between other variables and TFP is found. Foreign R&D has a greater impact on most of the smaller countries when domestic R&D has a larger impact on larger ones. So evidence (elasticity values) shows that direction of the technology transfer is mostly from larger countries to smaller ones.

In Coe,Helpman and Hoffmaister (1997), a sample for both developing and developed countries was constructed to investigate whether the spillover effect from industrialized economies to developing ones boost total factor productivity. The linkage through trade was examined and foreign R&D capital stock was constructed same as in Coe and Helpman (1995). Developing countries' openness to trade with developed economies is also considered as ratio of machinery and equipment imports to GDP. It should be noted that unlike Coe and Helpman (1995) imports of machinery and equipment was used to weight foreign R&D. Human capital is an explanatory variable in Coe,Helpman and Hoffmaister (1997). Education i.e. human capital is also interacted with foreign R&D capital stock to see whether the effect of foreign R&D on productivity is greater when domestic labor force is more educated. Finally, in this paper domestic R&D capital stock of developing countries is not included.

Since variances are not equal across all countries, estimation is made by Weighted Least Squares. Because some variables are non-stationary, "change" rather than level data is used. Alternative weights for both trade openness and foreign R&D capital stock is constructed. Machinery and equipment, manufactures, goods and services used to weight variables in three different equations. It is found that machinery gives better results than manufactures. Foreign R&D capital weighted with imports of total goods and services is not significantly different than zero which suggests that it has no effect on productivity. The argument is that because sum of imports consist of many consumer goods and services, its impact diminishes. Since those types of goods may have little effect on productivity. Coe, Helpman and Hoffmaister (1997) proves that imports of machinery and equipment is more efficient than its alternatives when it comes to increase total factor productivity via trade. Another different explanatory variable is used in this paper is market growth. By using the change in the log of a weighted average of industrialized countries’ GDP, it is shown that market growth is not significantly different from zero. It is proven that results of this work shows R&D spillovers, not an access to markets in growth. As a result, in Coe, Helpman and Hoffmaister (1997), it is found that on average a 1% increase in R&D capital stock of developed economies increase the output of developing countries by 0.06% via trade.

In Xu and Wang (1999), they also argue that using machinery and equipment imports as a weighting scheme gives better results. The share of capital imports are volatile in countries' total imports because they are consisting of consumption goods too. Results may be misleading since it is unlikely to transfer technology from various types of final goods. They also used the main equation in Coe and Helpman (1995) as a model and tested both weighting types. Results showed that, TFP is correlated with foreign R&D weighted by capital goods imports when it is not with foreign R&D weighted by total imports.

In Bruno van Pottelsberghe de la Potterie (2001), FDI was also used as a weighted method. Paper also argued that CH method for weighting foreign R&D has an aggregation bias. Trade, inward and outward FDI was used as independent variables. Domestic R&D of country j is divided by same country's GDP and weighted by flow of imports of goods and services of country i from j is used constructing foreign R&D of country i via trade. As a result, inward FDI has no significant effects on TFP. There is no technology transfer through inward FDI. On the other hand, the output elasticity of outward FDI flows is significant and positive. Results also show that outward FDI and imports reinforce each other.

In Bitzer and Kerekes, (2008), a new evidence contradicts with the Potterie and Lichtenberg (2001) was presented. They found out that inward FDI actually has a positive and significant effect on technology. They also emphasized that outward FDI does not provide technology transfer. This result contradicts with PL (2001). It is possible to say that FDI may transfer technology rather than functioning as a trojan horse. The difference between results of these two studies' can be interpreted by examining their samples. Since PL (2001) used a sample consisting of developed OECD economies, it is plausible to see why they have found a contradicting result.

In Coe, Helpman and Hoffmaister (2008) the model constructed in 1995 was again estimated with an expanded sample using DOLS. The new sample consists of 24 countries between 1971 and 2004. With a larger sample, elasticity of domestic R&D capital decreases in the G7 economies when it rises in non-G7 countries. Evidence confirms CH (1995) with more robust results. Human capital is also added as a significant independent variable. Alternative definitions for foreign R&D capital stock is also estimated. In the first one, domestic R&D capital of trading partners is weighted by bilateral import share weighted average as in CH (1995). In the second one, method proposed in Pottelsberghe de la Potterie (2001) is used to weight foreign R&D capital. As the last option, simple average of trading partners' is used to weight. The results suggest that bilateral import weights performs better than Pottelsberghe de la Potterie (2001) method. Simple average shows the worst performance among three.

In Gehringer, Zarsozo, Nowak and Danziger (2013), determinants of TFP for 17 EU countries between 1995 and 2007 was examined and they have focused on TFP calculation. They argued that it is more plausible to take country heterogeneity into account when estimating TFP. That's why they allowed country-spesific production technology rather than assuming standard capital and labor shares. They also used country spesific input coefficients in case there is endogeneity problem for the production function. They also claim that using sector level TFP tackles the aggregation bias problem with the country level TFP which arises from heterogeneity between sectors. They have used Augmented Mean Group Estimator (AMG) for estimation. TFP growth in 17 EU economies and 13 sectors examined and it is concluded that peripheral EU members have some problems when core countries performed better. Finally they constructed the empirical model with independent variables such as; R&D, human capital, trade openness, FDI, wages, structural funds and ICT (information and communications technology) investment. Exports and FDI both are significant and positive when human capital shows no significance.

In M.Henry, R.Kneller and C.Milner (2009), measured the effects absorptive capacity and technology transfer on the output levels. Their sample consists of 57 developing countries between 1970 and 1998. They constructed a technology frontier. In order to capture the effect of technology transfer foreign R&D to developing countries weighted by ratio of machinery imports from developed economies to their GDP. Production function is multiplied with the term;$e^{n+\varepsilon}$ where n stands for differences in level of productivity. If country is 100% efficient n equals to 1 so she can utilize the whole technology frontier since she has the highest absorptive capacity. Otherwise country stays below the frontier. They concluded that foreign R&D affects level of output positively. They have also found that human capital has negative effect in the Sub Saharan economies. So they argue that if institutional structure is for rent seeking rather than entrepreneurial activities, return to education causes wealth transfer instead of wealth creation. In M.Henry, R.Kneller and C.Milner (2009), efficiency scores are also presented and they indicate that trade affects technology transfer, absorption and efficiency positively.

In Weina and Xin (2014), a more recent research, positive and significant effects of technology spillover to China through international trade is found. This result also verifies that there is technology transfer via imports. Since China is a developing economy, it is plausible to say that the route of this transfer is to developing countries.

In Genç and Atasoy (2010), a panel data is constructed including Turkey. They found that there is a causal relationship from R&D efforts to growth. They also emphasized on the role of globalization and the importance of trade. The more a country opens up to world through trade, the more likely that it benefits from innovations in the foreign world.

In Meçik (2014) constructed a panel data for 24 OECD countries between 1990 and 2012.It is shown that R&D expenditures alongside with capital and labor is a positive and significant explanatory of the economic growth.

Beine, Docquier and Rapoport (2001) considered brain drain as a factor of economic growth. It is possible to define skilled migration as a foreign human capital. They've used a cross-section data with 37 developing economies for their analysis. However, since migration data with educational specification is not easily found, they used gross migration as a proxy for brain drain. In order to, control for additional effects Beine, Docquier and Rapoport (2001) used remittances since these also contributes to developing countries' GDP as a result of migration to developed countries. Another variable they used was immigration quotas since it is a restrictive property for migration to developed world. Wage differentials between countries are also considered as an incentive for migration. The results have shown that there is a positive and significant relationship between wage differentials and migration. It was also found out that brain drain is not significant. On the other hand human capital has positive effect on economic growth.

In Meçik (2015), effect of information and communication technologies (ICT) on labor productivity is investigated. It is shown that ICT has positive and significant effect on productivity in OECD countries between 1990- 2012. Meçik (2015) proved that these countries can increase productivity by using incentives for information technologies.

Lichtenberg (1992) is a very early research which used labor productivity as a dependent variable. It is found that private sector R&D investment has positive effect on labor productivity. They have also pointed out that R&D funded by government does not matter as much as private sector efforts.

Erdil, Cilasun and Eruygur (2013), also investigated the effect of R&D on labor productivity. They estimated a production function including capital-labor ratio, labor growth, human capital, FDI and openness. They have found that R&D expenditures have positive effects on labor productivity when FDI is insignificant. They argued that the reason behind this insignificancy arise from the countries in the sample. The countries in the sample are probably transferring technology rather than receiving. Human capital also turned out to be insignificant.

Bozkurt (2015), found out that there is causality from economic growth to R&D activities between 1998 and 2013 in Turkey. When an increase in real economic activities occurs, it positively affects R&D efforts. Turkey should allocate more resources for human capital investment and support collaboration between universities and private sector.

Akıncı and Sevinç (2013), used three types of R&D variables such as; higher education, public and business enterprise expenditures for R&D. They showed that there is no cointegration between any R&D variable and real GDP in Turkey. They emphasized that the reason behind this outcome is the insufficient investment in R&D in Turkey. However they also found out that there is a one way causal relationship from gross, private sector and higher education R&D expenditure to economic growth. As a policy advice, they have suggested that share of public sector and education R&D expenditures should be increased in GDP.

In Vergil and Sinay (2013), effects of technology transfer via capital goods and intermediate goods imports and human capital on economic growth is investigated for Turkey between 1989 and 2009. It is found out that there is a positive relationship between growth and technology transfer via imports however the effects of these variables are weak in Turkey. Johansen cointegration test proved that there is no relationship between variables in the long run. It is also found out that the effect of intermediate goods imports is higher than the capital goods imports.

2.2. Theoretical Notions about Technology

2.2.1 Rivalry, Excludability and Obsolescence

Romer (1990) has explained the basic attributes of a good embedded with technology. There are two fundamental features; rivalry and excludability. These notions are basically used to categorize goods as private and public in economics. In case of endogenous growth theories these two concepts are used to define goods embedded with R&D efforts. A good is purely rival when it can be used only by one agent in the economy and it is precluded to others. The good is purely non-rival if its use is not limited to others. A good is excludable when its use by others is legally prohibited i.e. intellectual property rights (IPR). A source code for a software protected by IPR would be a good example for that. Romer (1990), considered knowledge as a non-rival good which is partially excludable. It is however provided privately. By being non-rival, knowledge becomes a "good" open to other agents' use in the economy.

A good example for that could again be a source code for an operating system of a smart phone. If it's an open source code, everyone can use and develop it when the operating system can only be used by the people who own that particular smart phone(s). Since knowledge is partially excludable it can be interpreted that even though the technology developed by a firm, its use by the others is not prevented completely. Many examples of this situation can be especially seen in ICT (information and communication technologies) industry. When a software etc. is produced, even though the inventor firm keeps it as a secret, there is always the possibility of reverse engineering. In Romer (1990), knowledge is described as a "partially excludable" good.

Being a non-rival and partially excludable is one of the most important features of knowledge in the endogenous growth models because it enables the spillover effects. Knowledge spillover is an externality which is described to use when the knowledge for an invention can be reached and used by the other agents in the economy. So when an innovation occurs, other entrepreneurs benefit from that.

Obsolescence is a term used to describe the property of technological advancements which causes the old products to become useless. Once a new innovation occurs, it makes the old one obsolete. In case of physical capital, obsolescence occurs through depreciation. However, knowledge capital cannot be considered as same as physical capital. A newly innovated product becomes obsolete when a more recent and a better breakthrough occurs in this sector. This property is introduced by vertical innovation models such as Grossman and Helpman (1991). On the other hand, Romer (1990) presents a horizontally differentiated model. There is no obsolescence property considering the R&D efforts of countries. It turns out that Romer's model is not very realistic when it comes to its innovation properties. Quality Ladder in the Theory of Growth presents both horizontally and vertically differentiated intermediate inputs. In Coe and Helpman (1993), two different types of input functions are shown as follows;

$$D = n^{\frac{1}{a-1}} X$$

X stands for the intermediate inputs and n represents a country's cumulative R&D efforts. A vertically differentiated input function can be seen below;

$$D = \lambda^{I} X$$

Lambda stands for an input which is improved m times. If there is a same input improved m -1 times, then it is plausible to say that the more innovated input is λ times more productive than the old one. In other words, the old input becomes obsolete. I stands for the cumulative R&D efforts. It can be seen that when there is constant elasticity of substitution in the horizontally differentiated input function, the vertically differentiated version shows the level of innovation via power of lambda which depends on the level of innovation.

Grossman and Helpman (1991), shows that both approaches create externalities. In the variety-based (horizontal) approach, externalities can be observed explicitly. When an innovation occurs, it lowers the cost of upcoming R&D projects. In case of quality ladder approach, a breakthrough in the R&D efforts of an agent causes other researchers to give up their efforts on that improvement so that they can start working on the next level. In both cases, it can be seen that R&D efforts create externalities in the economy. Two approaches differentiate when it comes to their welfare properties.[1]

2.2.2 Total Factor Productivity

Growth accounting is an efficient way to investigate the factors of production. The main factors of production are labor and capital. In Neo-classical Growth Theory, it is a well-known fact that capital exhibits diminishing returns to scale with a given amount of labor. So the production function is a concave function with homogenous of degree one and constant returns to scale. This feature of Neo-classical growth theory is shown in the production function below with a positive constant.

$\lambda > 0$

$F(\lambda K, \lambda L) = \lambda F(K,L)$

However, the share of labor and capital do not solely explain the variations in economic growth. The "unexplained part" is called "Solow Residual". Production function with exogenous technology in neo-classical sense is shown below.

$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha}$

Log of production function is taken as follows;

$\log Y_t = \log A_t + \alpha \log K_t + (1-\alpha)\log L_t$

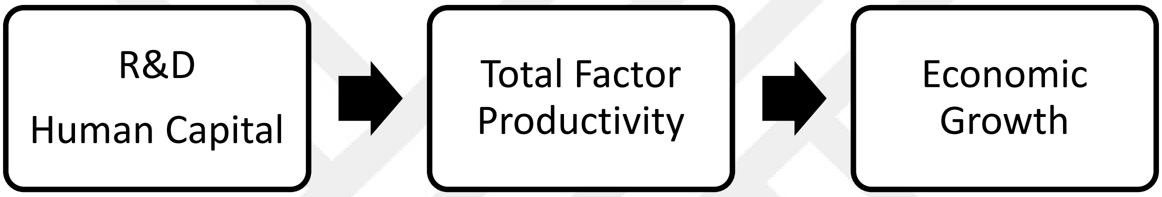
In the equation above first term on the right hand side is called as Solow Residual a.k.a. Total Factor Productivity (TFP). When TFP is left alone, the result is as follows.

[1] Welfare properties of quality ladder approach are explained in Section 1.2.5

$$\log A_t = \log Y_t - \alpha \log K_t - (1-\alpha)\log L_t$$

It can be seen that TFP is what is left after subtracting the share of capital and labor from output. So the growth in productivity also a factor for GDP growth. The technology is the main reason behind improvements in productivity and the most significant way of improving technology is innovation. Inventing new products which are more efficient in production increases the amount of output within a given period of time. There are two main factors for producing higher technological products; research and development efforts and human capital. The direction of causality between variables mentioned above can be seen in Figure 1.

Figure 1: The Relationship between Technology and Growth



2.2.3 Research and Development (R&D)

Improvements in technology depends on the innovations made by researchers. Successful research and development efforts result advancements in technology and increase in knowledge capital. It is possible to say that technological improvements are the outcomes of the interaction of accumulated knowledge and human capital. Grossman and Helpman (1991) particularly focused on modelling R&D efforts of the firms. They showed that there is monopolistic competition in their model. It is assumed that because of the nature of the property rights in each industry there is a unique quality leader. The leader firm is exactly one step ahead of its closest rival. Firms in an industry compete each other in order to innovate the next step in the quality ladder for a targeted product.

2.2.4 Human Capital

The main source of human capital is education. Educated people in the labor force creates the human capital of a country. The more people are educated in higher levels, the more qualitative human capital a country has. An increase in the number of people who enrolled in tertiary education is an example for that. In empirical work, number of people who are enrolled in or the enrollment rate of secondary, tertiary education etc. are used as proxies for human capital measurement.

Romer (1990), has two main assumptions considering human capital. First, more human capital causes an increase in production of new designs which occurs through innovation. Second, as the innovation increases, it leads to a higher knowledge capital stock which turns into a higher productivity for the researchers. Romer, compares two engineers who are working in different time periods. The engineer who is working today is more productive than the one in the past only because she/he has access to a greater amount of knowledge capital. This outcome arises because of the cumulative characteristic of knowledge. It should be noted that in Romer (1990), stock of knowledge and human capital are linear functions. Being knowledge capital linear is a crucial assumption since this is why there could be limitless growth in this model. According to this assumption, marginal productivity of human capital in the research sector increases in proportion to knowledge capital stock. Evolution of stock of knowledge is represented as below;

$$\dot{A} = \delta H_A A$$

In the equation, H_A stands for the total amount of human capital in research sector, δ is a productivity parameter and A is the previous stock of knowledge. The last variable represents the accumulated knowledge to date which is available to all agents in the economy. This equation represents, public good characteristic of knowledge and shows the interaction between human and knowledge capital.

The difference between human and knowledge capital is described in Jeffrey Parker's Macroeconomic Theory (2011). The most important difference is about being a public good or not. When the knowledge capital could be a public good since its non-rival and partially excludable, human capital could not be. Even though a successful innovation produced by a researcher could be a public good, researcher himself/herself as a human capital is not embodied with the same properties. Even though learning from a teacher makes you a more qualitative person, there cannot be a spillover effect in this kind of situation.

2.2.5 Return to Scale Properties and Externalities

Neo-classical growth theory suggests that there is constant returns to scale in production function with a homogenous of degree one. The technology is considered as an exogenous variable and the production function is in a concave form. Since the factors affecting the technology are given and the other factors (capital, labor) exhibit constant returns to scale, there is diminishing marginal return. This situation can be explicitly seen in Neo-classical Solow Growth Model. With the emergence of endogenous growth models, technology is considered as an endogenous variable. As it was clearly emphasized in Romer (1986) and Romer (1990), technology was observed as a factor with increasing returns to scale. Even though capital exhibits diminishing returns to scale with the same amount of labor and technology would result with a limitless growth. When the knowledge spillover in a market also considered, the economy as a whole can produce with increasing returns to scale. This is one of the most important features of the endogenous growth models and the most significant point where it differentiates itself from the neo-classical growth theory.

Knowledge spillovers are also called as externalities. Any firm benefits from other agents' innovation in an industry. This kind of positive externality is a source for increasing returns to scale. Grossman and Helpman (1991) explains the welfare implications of knowledge spillovers in their theoretical model. Externalities created by innovation is twofold. There is a positive externality which arises because when a new innovation occurs, consumers can purchase a higher quality product with the same price. This positive externality is the combination of two effects. The consumer surplus effect (occurs through the life of the new product) and intertemporal spillover effect (occurs during the life of all later products because there are always new innovations climbing up the quality ladder). The second (negative) externality is the business stealing effect. When a firm realizes a successful innovation it obliterates the producer surplus of the displaced firm. A multiplier effect occurs because the owners of the displaced firm loses income. This lost turns out as a decrease in demand and less profit for other industry leaders. The number of innovations on a product determines whether the positive or negative externalities are stronger. When there is low and high number of innovations the business stealing effect is greater. For the intermediate values of innovations, consumer surplus and intertemporal spillover effects combined are larger.

Externalities can also be considered for an open economy case. Countries take advantage of world's R&D capabilities via imports. Intermediate goods imports is a good intermediary for that purpose. Especially machinery and equipment imports are used to measure spillover effects for an open economy case. Multinational Enterprises (MNE's) are also a source for technology transfer.[2] Since they invest on an international level, they are very efficient intermediaries to transfer R&D efforts in a country to another via merger and acquisitions etc. There are some necessities for this transfer to occur. The country which is receiving the foreign direct investment (FDI) is called the "host" country. The country which sending the FDI on the other hand is named as the "home" country. If the level of technology and education in the host country is too low, she won't be capable enough to adopt this technology. The technology transfer may fail in this case. It means that productivity level in the host country stayed unchanged or did not increase significantly. The opposite is also possible. If a country has a dramatically high level of technological knowledge than it is possible that the incoming transfer would have no contribution. In order to adopt and make use of technology from the outside world, the host country should have a productivity level above a threshold value which can be calculated considering the home countries' productivity levels.

Properties of Romer and Grossman and Helpman's endogenous growth models are compared in Table 1. Romer, himself admits that his model is not a realistic one when it comes R&D market, in his paper. In Grossman and Helpman (1991) vertical innovation was examined. When a new step is climbed in the quality ladder, old one becomes obsolete. This situation leads to monopolistic competition where companies compete each other in order to make a breakthrough and become the leader in an industry.

[2] Spillover effect via FDI and trade is an important subject in empirical literature and it can be found in section 1.1

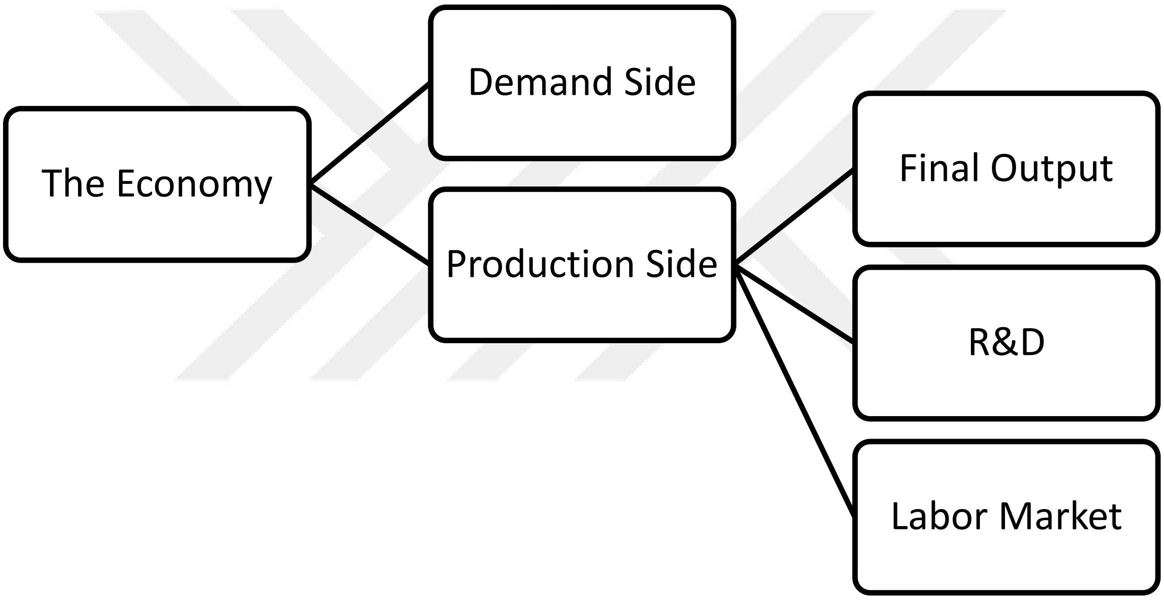
Table 1: Comparison of Theoretical Models

Properties	**Romer**	**Grossman and Helpman**
Returns to Scale	Increasing	Increasing
Obsolescence	Does not exist	Exists
Innovation	Horizontal	Vertical
R&D Market	Perfect Competition	Monopolistic Competition

3 THEORETICAL MODEL

The model created in Grossman and Helpman (1991) is used as a base for this research. The theoretical model is mainly explaining how research and development efforts function and its effects on economic growth. There is monopolistic competition in the R&D market. The innovation efforts of the agents in the economy is vertically differentiated. It is called quality ladder approach and it is more realistic comparing to a horizontal one in case of a R&D based model. Breakdown of the model is represented in Figure 2.

Figure 2: Market Composition



3.1 Demand Side

Consumers optimize their utility subject to an intertemporal budget constraint. Quality of goods they demand is defined by an innovation parameter. Since this is a vertical model, number of innovations is also considered. The intertemporal utility function is as follows;

$$U = \int_0^\infty e^{-pt} \log u(t)\, dt \qquad (1)$$

$$\log u(t) = \int_0^1 \log[\sum_j q_{jt}(\omega) d_{jt}(\omega)]\, d\omega \qquad (2)$$

In these equations, $q_j(ɯ) = \Lambda^j$ stands for the quality of a good and Λ^j represents how many times the product is innovated. Consumption of quality j of good ɯ is shown as; $d_{jt}(ɯ) = E(t) / p_{jt}(ɯ)$. This equation is simply the demand function. The intertemporal budget constraint is given below;

$$\int_0^\infty e^{-R(t)} E(t)dt \tag{3}$$

Flow of spending at time t is shown as $E(t) = \int_0^1 \sum_j p_{jt}(ɯ) d_{jt}(ɯ)\, dɯ$ when R(t) is the cumulative interest rate. Solution to consumer's optimization problem is solved with the help of a Hamiltonian Function;

$$H = \int_0^\infty e^{-pt} \{ lnE(t) + \int_0^1 \ln q(ɯ) - \ln p(ɯ)\, dɯ \}\, dt + \mu(t) \int_0^\infty e^{-R(t)} E(t)dt \tag{4}$$

The second terms (with q and p) in the first parenthesis can be ignored since they do not depend on t. This also means that consumer has no influence on these variables. The consumer makes his/her maximization decision in two steps. First he/she allocates E(t) to maximize u(t), then maximizes the Hamiltonian function with respect to time. First derivation with respect to E(t);

$$0 = e^{-pt} \frac{1}{E} + \mu(t)\, e^{-R(t)} \tag{5}$$

$$e^{-pt} \frac{1}{E} = -\mu(t)\, e^{-R(t)} \tag{6}$$

Natural logarithm of both sides are taken;

$$-pt - \ln E = \ln(-\mu(t)) - R(t) \tag{7}$$

Finally, second derivative with respect to t gives the solution below;[3]

$$-p - E' / E = - R(t)' \tag{8}$$

[3]μ is omitted in the second derivation because it is constant. It can be proven by deriving Hamiltonian with respect to state variable; dH/dy = - μ' = 0

If the change in expenditure is left alone on the right hand side. Growth rate of consumer expenditure can be observed explicitly.

$R(t)' – p = E' / E$ (9)

3.2 Production Side

In this model, properties of vertical innovation and monopolistic competition can be observed.

- New products make the old ones obsolete.
- Quality leader charges mark-up price over marginal cost.
- There is imperfect competition.
- Amount of profit is the same in all industries so the competitors are indifferent choosing a market to enter.

3.2.1 Profit Maximization

It is assumed that because of the nature of the property rights in each industry there is a unique quality leader. This leader firm is exactly one step ahead of its closest rival. All "state of the art" products have the same price; $P = \Lambda w$. Price yields demand per product of; $E/ \Lambda w$. The profit function of the firm is as follows;

$$\pi = PE / \Lambda w – wE/ \Lambda w \quad (10)$$

$$\pi = \Lambda w E/ \Lambda w - wE/ \Lambda w \quad (11)$$

$$\pi = E/\Lambda w\ (\Lambda w – w) \quad (12)$$

$$\pi = (1 – 1/\Lambda)\ E \quad (13)$$

Firms in an industry compete each other in order to innovate the next step in the quality ladder for a targeted product. If a firm keeps R&D intensity i for the time interval dt, it will reach the next step in the quality ladder with a probability idt. A unit of R&D activity requires α_i unit of labor per unit of time. When the leader succeeds in a research project, it gains a two-step advantage over its closest rival. This situation gives leader the advantage to increase its price to $\Lambda^2 w$. This situation causes a flow of marginal profit of leader equals to;

$$\pi = (1 - 1/\Lambda^2)\, E \qquad (14)$$

Profit before the research success is $\pi = (1 - 1/\Lambda)\, E$. Thus the difference gives the incremental profit; $(1 - 1/\Lambda)\, E/\Lambda$

This is clearly less than the profit that accrue to a non-leader who achieves a research success which equals to; $(1 - 1/\Lambda)\, E$.

3.2.2 R&D Market

The stock market value of the firm i.e. prize for a research success is given by v. Maximizing condition for the expected net benefit from R&D equals to $vidt - w\alpha_i idt$. Aggregate intensity of research by the many entrepreneurs who target their R&D efforts at the leader's product is given by i. Expected rate of return in shares per unit time equals to $(\pi - v') / v - i$.

No arbitrage condition can be written, using maximizing condition, $v = w\alpha_i$ as follows;

$$\pi / w\alpha_i + w' / w = R' + i \qquad (15)$$

Finally, the relation between R&D market (production side) and spending (demand side) is shown below[4];

$$\pi / \alpha_i = R' + i \qquad (16)$$

(13) and (9) are plugged into (15);

$$\frac{\left(1-\frac{1}{\Lambda}\right)E}{\alpha_i} = -p - E' / E + i \qquad (17)$$

The growth in spending is left on the left hand side;

[4]w(t) = 1 i.e. labor is taken as numeraire for all t.

$$E^{'} / E = \frac{\left(1-\frac{1}{\Lambda}\right)E}{\alpha_i} - p - i \tag{18}$$

When $E^{'} / E = 0$ (no growth in spending) the initial condition equals to;

$$\frac{\left(1-\frac{1}{\Lambda}\right)E}{\alpha_i} = p + i \tag{19}$$

3.2.3 Labor Market

It is assumed that labor is employed in two sectors; manufacturing and R&D. Total employment in manufacturing equals to $\int_0^1 E(t)/P(t)\, d\omega = E(t) / \Lambda$ when total employment in R&D sector equals to $\alpha_i i$. Equilibrium in the labor market is given by;

$$\alpha_i i + E(t) / \Lambda = L \tag{20}$$

3.3. Determinants of Growth Rate

Solving (19) and (20) for i (Aggregate intensity of research) when there is no growth in spending i.e. E'/E=0 gives;

$$i = \frac{\left(1-\frac{1}{\Lambda}\right)L}{\alpha_i} - p/\Lambda \tag{21}$$

A higher equilibrium can be achieved due to two terms in this equation;

- When there is a larger labor force, aggregate intensity of research grows faster.
- An increase in Λ also causes a jump in technology and provides growth.

3.4 Optimal Growth Rate

Lifetime utility function is presented as follows where p stands for the discount rate.

$$pU = \log E - \log \Lambda + (i/p) \log \Lambda \tag{22}$$

Equation (22) is maximized subject to (20) with respect to i gives the optimal intensity of innovation[5];

$$i^* = L/\alpha_i - p / \log\Lambda \quad (23)$$

Difference between Optimal and Equilibrium Growth Rate can be shown as follows;

$$i^* - i = p/ \Lambda (L/ p\alpha + 1 - \Lambda \log\Lambda) \quad (24)$$

3.5 Externalities

The positive externality (consumer surplus + intertemporal spillover) is measured by $\log\Lambda / P$. The negative externality is $(\Lambda - 1) / (p + i)$. The nominator shows the fall of other firms' profits caused by an innovation. Denominator is the discount rate with the expected rate of arrival of the next innovation.

When the formula for difference between optimal and equilibrium growth rate is examined, it can be seen that a larger L/α (R&D efficiency of labor) most probably leads to a higher optimal growth rate of aggregate innovation than the equilibrium rate.[6]

[5] E in equation $pU = \log E - \log \Lambda + (i/p)\log \Lambda$ is substituted with E in subjective function, $\alpha i i + E(t) / \Lambda = L$. Then it is derived with respect to i.

[6] A detailed intuition for externalities can be found in section 1.2.5.

4 DATA AND METHODOLOGY

4.1 Data

Empirical research is mainly based on research and development expenditures and its relationship between productivity in 23 countries between 2002 and 2011. There are 230 observations. Since there are more than one cross section and time unit, panel data analysis will be implemented. Independent variables in the model are domestic and foreign R&D capital stock, fixed capital formation. Dependent variable is labor productivity. Countries in the sample can be found in Table 2. Data for R&D variables, Real GDP, fixed capital formation are taken from OECD Database. Data for total employment is obtained from Total Economy Database. Data for Machinery and Transport Equipment Import[7] is taken from UN Comtrade. Raw data for the R&D Capital Stock is the Private Sector R&D Expenditures.

Table 2: Countries in the Sample[8]

G7			
Canada	Australia	Israel	Slovenia
France	Austria	Korea	Turkey
Germany	Belgium	Mexico	
Italy	CzechRepublic	Netherlands	
Japan	Finland	Norway	
United Kingdom	Spain	Poland	
United States	Hungary	Portugal	

[7] SITC Code for this data is 7 and it is bilateral imports between countries in the sample.
[8] Even though China and Russia are not in the sample, descriptive statistics for these two countries are also presented. They are not included in the sample because they are outliers, scatter plot can be found in the Appendix D.

4.2 Methodology

The variables used in this research are constructed in different methods. Explanatory variables are grouped in two sections and it can be seen in Figure 3. All variables are real with 2010 as base year. Bilateral Machinery and Equipment Imports are taken in current values. They are transformed into real variables with 2010 as base year using GDP Deflator. All variables are in US dollars. Total Employment is the number of people who are employed and it is in thousands when all the other variables are in millions. Domestic R&D capital stock is calculated using perpetual inventory method on R&D expenditures between 2002 and 2011.[9] Notation for all variables is presented in Table 3.

Figure 3: Explanatory Variables

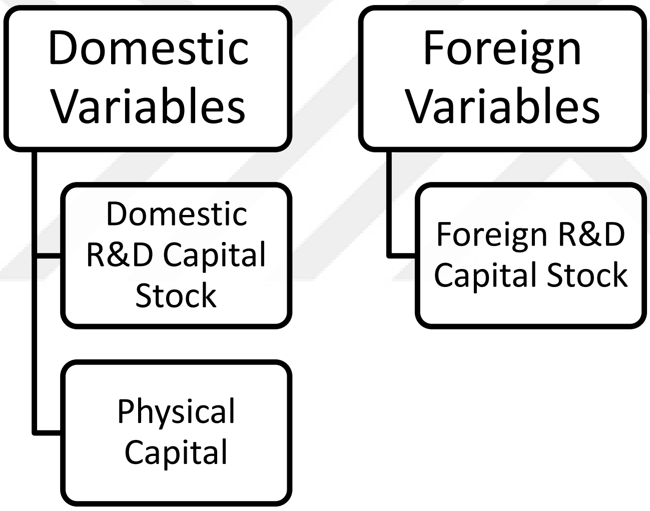


Table 3: Notation for Variables

Labor Productivity	Y_{it}/L_{it}
Domestic R&D Capital	R_{it}
Foreign R&D Capital	F_{ijt}
Physical Capital	K_{it}

[9] Detailed calculation of PIM (Perpetual Inventory Method) can be found in Appendix A.

Labor productivity is calculated as the ratio of Real GDP to total employment. As a result, the value produced per person employed becomes the dependent variable. Y_{it} (i and t represent the country and year) stands for Real GDP when L_{it} represents total employment. Calculation is as follows;

$$\frac{Y_{it}}{L_{it}}$$

Domestic R&D Capital Stock is the cumulative R&D expenditures of the countries in the sample. This variable is used as a stock rather than a flow. Because the fluctuations in flow variable may result in a biased result. Secondly, since there are data limitations in R&D expenditure, stock variable is useful to capture the cumulative effect. It is also plausible to have a stock variable to measure the knowledge capital. Agents in the economy do not only use the knowledge capital produced in a certain time period, they would also use all the knowledge they can gather from the past periods.[10] The other domestic variable is physical capital. It is used to capture the effect of physical capital on labor productivity. An increase in the amount of capital may give rise to increase in efficiency of labor. As the capital stock rises, this might also prevent the diminishing labor productivity. It should also be noted that machines with higher efficiency would make labor more productive. It is expected that change in the physical capital stock would have a positive effect on productivity.

Foreign R&D Capital is used to capture the spillover effect (externalities). The main methodological argument in this issue is about weighting scheme. In order to create a transmission mechanism for the R&D capital stocks of countries, total imports, capital imports and FDI are generally used. In Coe and Helpman (1995), total imports of countries are used. However, this method might give a biased result. Because total imports of goods and services consist of all types of products including; food, beverages and other final products. It is reasonable to think that, it is not possible to transfer technology through all types of goods. In order to avoid this kind of biased result, Coe, Helpman and Hoffmaister (1997) used imports of machinery and transport equipment to GDP ratio to weight R&D capital. GDP of the importers is used to capture country specific effects. Xu and Wang (1999) also tested the performance of

[10] In 1.2.4, it was mentioned that Romer explained the growth in knowledge by using the interaction between human capital and previous knowledge capital stock.

capital goods imports as a weighting scheme against total imports. They have found that capital goods imports give better results. Import of machinery and transport equipment is also used as a weighting scheme in this research. Because of the biased results occur through total import of goods and services and the content of the machinery and transport equipment classification. It can be seen that most of the goods embedded with high technology can be found under this classification in Table 4.[11] F_{ijt} represents the foreign R&D capital stock and i stands for the importer when j shows the exporter country. I_{ijt} is the bilateral machinery and transport eq. imports (capital good import) of the country i from country j. Foreign R&D Capital Stock is calculated as follows;

$$F_{ijt}=\sum_{t=2002}^{t=2011}\frac{I_{ijt}}{Y_{it}}R_{jt}$$

Table 4: High Technology Good Imports (UN Classification)

Machinery and Transport Equipment	7
Office machines and automatic data-processing machines	75
Aircraft and associated equipment; spacecraft	792
Telecommunications and sound-recording and reproducing apparatus and equipment	76

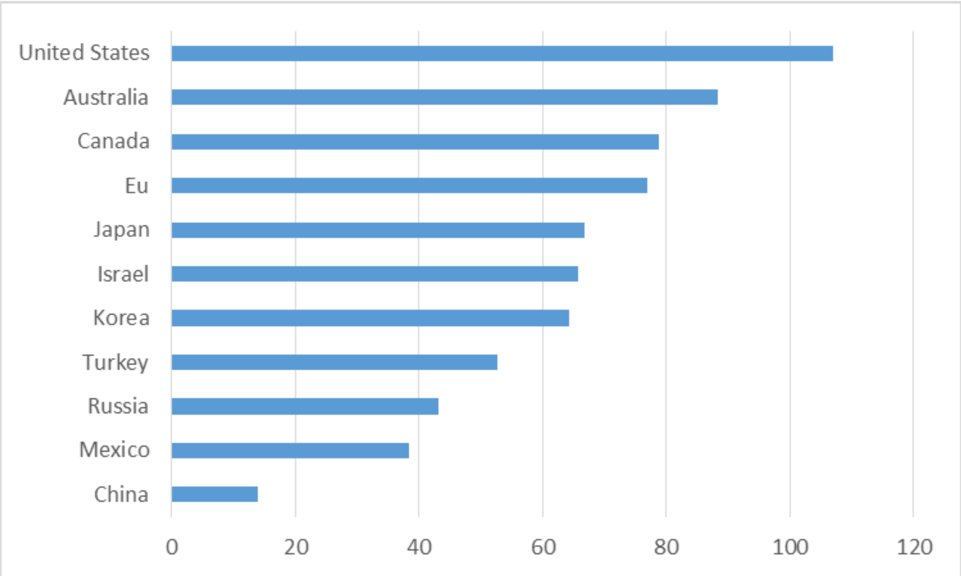
R_{jt} is the domestic R&D capital stock of the exporter country. Each country's R&D capital stock is multiplied with the bilateral capital goods exports to another country to importer's GDP ratio. This variable is the foreign capital stock of the importer country and captures the spillover effect.

[11] High Technology industries consists of aircraft and spacecraft, office, accounting and computing machinery, radio, tv and communications equipment, medical, precision and optical instruments and pharmaceuticals.

5 DESCRIPTIVE STATISTICS

Research and Development is one of the most significant determinants of the productivity. It is plausible to examine these two variables and their trends through the years, in order to understand how these variables behave. In Figure 4, labor productivity in different countries in 2011 is presented.[12] United States is the leader country when China has the lowest labor productivity levels in the sample.Turkey is in the 8th place with productivity levels exceeding Russia, Mexico and China. When the closest follower of United States is Australia, Europe has the 4th place. Private Sector Research and Development Capital Stocks of these economies are presented in Figure 5.[13]United States is the leader when Japan has the 2nd and China has the 3rd place. After 2005 China's R&D capital stock significantly increased. Eventhough Turkey has the lowest capital stock among the countries in the sample, after 2006 Turkey's R&D capital also increased. In 2011, Mexico and Turkey had the capital stock which is almost equal to each other. It can be seen that foreign R&D capital of Israel is the highest in Figure 6. United States is not the leader most probably due to the R&D received by the countries is weighted using the ratio of imports to their GDP.

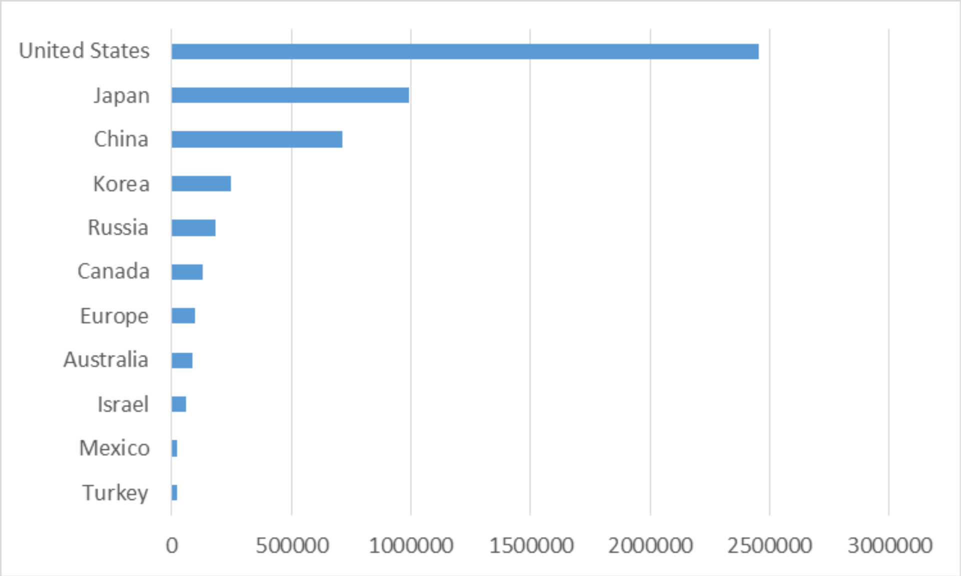
Figure 4: Real GDP per employee (Thousand US Dollars in 2011)



Source: Author's calculation

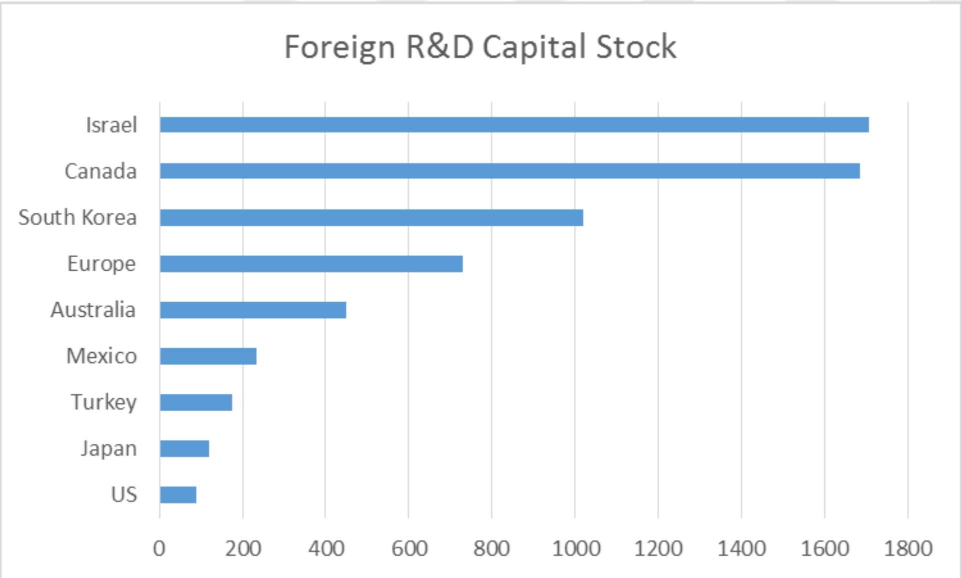
[12] European economies (including Finland and Norway) are grouped under the name of Europe.
[13] R&D expenditures in 2011 are not included.

Figure 5: Domestic R&D Capital Stock (Million US Dollars in 2011)



Source: Author's calculation

Figure 6: Foreign R&D Capital Stock (Million US Dollars in 2011)



Source: Author's calculation

Bilateral capital goods import shares can be observed in Table 47[14] in order to understand the trade pattern between countries. The highest values can be seen between Germany and Austria, Canada and United States. U.S. and Germany are the greatest exporters of machinery and transport equipment. The largest share in Turkey's imports belongs to Germany. France, Hungary, Israel and Germany are the major importers from Turkey.

Table 5: Descriptive Statistics for All Economies

Variable	Obs	Mean	Std. Dev.	Min	Max
LP	230	1.841412	0.11879	1.569735	2.066621
BRD	230	4.755623	0.697114	3.561365	6.389769
FRD	230	2.565731	0.475148	1.704621	3.887333
CAP	230	5.240652	0.532143	4.059181	6.512911

LP: Labor Productivity, BRD: Domestic R&D Capital Stock, FRD: Foreign R&D Capital Stock, CAP: Physical Capital

The Sample is split into two parts in Table 5 and 6. In "All Economies" table, all of the countries in the sample can be observed. In the second table, descriptive statistics for only G7 economies are presented. The highest mean belongs to physical capital stock in both samples. It is plausible since capital is one of the major factors of production. Private domestic R&D capital has the highest standard deviation in both samples. It can be seen that standard deviation of all variables are lower in the second sample. Since it consists of seven major economies in the world, it is a more homogenous sample. Mean of all variables are higher in the second sample except foreign R&D capital stock, it is slightly below to the "All Economies" sample. Standard deviation of labor productivity in G7 countries is significantly lower than the other sample. It is also expected since all of these countries' productivity levels are above the average of the 23 countries in 2011 except Japan.

[14] Table 47 can be found in Appendix C.

Table 6: Descriptive Statistics for G7

Variable	Obs	Mean	Std. Dev.	Min	Max
LP	70	1.905408	0.054813	1.795108	2.029238
BRD	70	5.555923	0.446933	4.988287	6.389769
FRD	70	2.412389	0.434642	1.684008	3.252738
CAP	70	5.804145	0.314058	5.368376	6.512911

LP: Labor Productivity, BRD: Domestic R&D Capital Stock, FRD: Foreign R&D Capital Stock, CAP: Physical Capital

Table 7: Descriptive Statistics for Countries Excluding G7

Variable	Obs	Mean	Std. Dev.	Min	Max
LP	160	1.813413	0.1281707	1.569735	2.066621
BRD	160	4.405492	0.4559572	3.561365	5.395854
FRD	160	.9271244	0.554392	-.0414672	2.414048
CAP	160	4.994124	0.4050832	4.059181	5.665515

LP: Labor Productivity, BRD: Domestic R&D Capital Stock, FRD: Foreign R&D Capital Stock, CAP: Physical Capital

Table 8: Descriptive Statistics for Unilateral Technology Transfer

Variable	Obs	Mean	Std. Dev.	Min	Max
LP	90	1.713889	.0645683	1.569735	1.818141
BRD	90	4.200825	.5007833	3.561365	5.395854
FRD	90	2.731027	0.548377	1.793824	3.872477
CAP	90	4.949199	0 .4620536	4.059181	5.665515

LP: Labor Productivity, BRD: Domestic R&D Capital Stock, FRD: Foreign R&D Capital Stock, CAP: Physical Capital

6 EMPIRICAL MODEL

The model is based on Coe and Helpman (1993). In their paper, Coe and Helpman formulated an empirical model in order to estimate Total Factor Productivity. They've used domestic R&D capital and foreign R&D capital as independent variables. In this research, the empirical model is as follows;

$$logLP_{it} = \alpha_i + \beta_i^1 logBRD_{it} + \beta_i^2 logCAP_{it} + \varepsilon_{it}$$

$$logLP_{it} = \alpha_i + \beta_i^1 logBRD_{it} + \beta_i^2 logCAP_{it} + \beta_i^3 logFRD_{it} + \varepsilon_{it}$$

First equation represents a closed economy. There is no foreign R&D capital stock in this case. Spillover effects are captured in the second equation. All variables are in logarithmic forms. The notation was presented in Table 6. This model is differentiated from Coe and Helpman (1993). First, dependent variable is chosen as labor productivity rather than total factor productivity. Second, capital goods import are used to weight the foreign R&D. The reasoning behind this choice is explained in Data and Methodology Section. Finally, Fixed Capital Formation is used as another domestic variable in order to control for the change in the physical capital stock of countries. ε_{it} stands for the error term and α_i is the intercept.

7 EMPIRICAL ANALYSIS

7.1 Test Results for All Economies and G7 Samples

7.1.1 Closed Economy

Variables without foreign R&D capital stock are tested in this section. It is assumed that there are no externalities. Two different samples which are presented in Table 5 and 6 are estimated. Test results for both samples are presented in the following tables. Hausman Test Results can be seen in Table 9. It is shown that in both cases p value is smaller than 0.05. Null Hypothesis is rejected and Fixed Effect estimation is chosen due to these results.

Table 9: Hausman Test for Closed Economy

	All Economies	G7
chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)	77.23	44.76
Prob>chi2	0.0000	0.0000

In Table 10, Modified Wald test results can be seen. It is proven that there is heteroscedasticity problem in both samples. Null hypothesis which suggests that there is no heteroscedasticity is rejected.

Table 10: Heteroscedasticity Test for Closed Economy

Modified Wald test for groupwise heteroskedasticity in fixed effect regression model		
H0: sigma(i)^2 = sigma^2 forall i		
	All Economies	G7
chi2 (24)	1623.10	39.43
Prob>chi2	0.0000	0.0000

Durbin Watson and Baltagi-Wu tests are done for the fixed effect model and the results are presented in Table 11. Critical Value for these tests is 2. Since all test values are below critical level, it is shown that there is auto correlation problem.

Table 11: Auto-Correlation Tests for Closed Economy

	All Economies	G7
Modified Bhargava et al. Durbin-Watson	.37419081	.60191354
Baltagi-Wu LB	.78717813	.96044231

Table 12: Cross Sectional Dependency Tests for Closed Economy

	All Economies	G7
Pesaran's test	Pr = 0.0000	Pr = 0.0843
Friedman's test	Pr = 0.0022	Pr = 0.0314
Critical values from Frees' Q distribution alpha = 0.10 : 0.2559 alpha = 0.05 : 0.3429 alpha = 0.01 : 0.5198	Frees' test = 5.152	Frees' test = 1.435

Three different cross-sectional dependency tests are conducted. All tests showed that there is cross sectional dependency in the large sample. In G7 sample, only Pesaran Test indicated that there is no cross sectional dependency. Null hypothesis is rejected according to Frees and Friedman test results. It can be said that there is also cross sectional dependency between G7 countries.

7.1.2 Open Economy

Foreign R&D capital stock is included as an explanatory variable in this model in order to capture the spillover effect between economies. Test results for the open economy case are as follows;

Table 13: Hausman Test for Open Economy

	All Economies	G7
chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)	48.76	17.02
Prob>chi2	0.0000	0.0007

Hausman Test results showed in Table 13. Null P values are smaller than 0.05. Hypothesis for both samples are rejected. Both samples should be estimated using fixed effect model. An estimator should be chosen which can be control for the fixed effect.

Table 14: Heteroscedasticity Tests for Open Economy

Modified Wald test for groupwise heteroskedasticity in fixed effect regression model		
H0: sigma(i)^2 = sigma^2 forall i		
	All Economies	G7
chi2 (24)	3222.73	229.79
Prob>chi2	0.0000	0.0000

Auto correlation test results are presented in Table 15. In the open economy, there is also auto correlation problem. Values for both samples are below 2.Cross-sectional dependency test results can be seen in Table 16. Pesaran, Friedman and Frees' tests showed that there is cross sectional dependency in the large sample. However, between G7 countries, only Frees' test indicated a cross sectional dependency problem. In order to, avoid any biased results that may arise because of cross sectional dependency, the estimation method would be chosen considering this problem.

Table 15: Auto Correlation Tests for Open Economy

	All Economies	G7
Modified Bhargava et al. Durbin-Watson	.35433844	0.5028
Baltagi-Wu LB	.77259252	0.86873322

Variance inflation factor, indicated that there is no multi collinearity between variables. In Table 19, it is shown that all VIF (variance inflation factor) values are smaller than 10. Mean VIF is also 3.14 which is a very low value.

Table 16: Cross Sectional Dependency Tests for Open Economy

	All Economies	G7
Pesaran's test	Pr = 0.0000	Pr = 0.7794
Friedman's test	Pr = 0.0128	Pr = 0.3276
Critical values from Frees' Q distribution alpha = 0.10 : 0.2559 alpha = 0.05 : 0.3429 alpha = 0.01 : 0.5198	Frees' test = 4.702	Frees' test = 0.905

Table 17: Correlation Matrix for All Economies

e(V)	BRD	CAPITAL	FRD	_cons
BRD	1			
CAP	-0.3026	1		
FRD	-0.4783	0.0956	1	
_cons	-0.6638	-0.4961	0.2182	1

Table 18: Correlation Matrix for G7

e(V)	BRD	CAPITAL	FRD	_cons
BRD	1			
CAP	0.0252	1		
FRD	-0.9355	-0.2656	1	
_cons	-0.9631	-0.2925	0.9608	1

Table 19: Multi Collinearity Test

	All Economies		G7	
Variable	VIF	1/VIF	VIF	1/VIF
CAP	5.22	0.191699	8.69	0.115051
BRD	3.80	0.263105	7.79	0.128399
FRD	1.78	0.561206	4.22	0.236885
Mean VIF	3.60		6.90	

7.2 Test Results for All Economies Excluding G7

7.2.1 Closed Economy

G7 countries are excluded in this sample in order to see how the rest of the sample performs without major economies. This is another heterogenous sample. Hausman Test result for the closed economy shows that fixed effect model should be chosen.

Table 20: Hausman Test for Closed Economy

chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)	7.53
Prob>chi2	0.0232

Modified Walt Test, indicates that there is heteroskedasticity problem since P value is below 0.05. Durbin-Watson and Baltagi-Wu tests for auto correlation shows that there is auto correlation in the sample. Both test values are smaller than 2. Finally cross sectional dependency tests are conducted. Pesaran, Friedman test values are below 0.05 and Frees' result is greater than the three critical values. It is plausible to say that there is cross sectional dependency in the closed economy.

Table 21: Heteroscedasticity Test for Closed Economy

Modified Wald test for groupwise heteroskedasticity in fixed effect regression model	
H0: sigma(i)^2 = sigma^2 forall i	
chi2 (24)	2251.68
Prob>chi2	0.0000

Table 22: Auto-Correlation Tests for Closed Economy

Modified Bhargava et al. Durbin-Watson	0.3528356
Baltagi-Wu LB	0.76934137

Table 23: Cross Sectional Dependency Tests for Closed Economy

Pesaran's test = 7.840	Pr = 0.0000
Friedman's test = 34.814	Pr = 0. 0026
Critical values from Frees' Q distribution alpha = 0.10 : 0.2559 alpha = 0.05 : 0.3429 alpha = 0.01 : 0.5198	Frees' test = 3.242

7.2.2 Open Economy

Foreign R&D capital stock is included as a variable in the open economy model. Hausman Test Result showed that fixed effect estimation should be used. Heteroscedasticity tests result equals to 0. Null hypothesis is rejected and it is shown that there is heteroscedasticity in the sample.

Table 24: Hausman Test for Open Economy

chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)	30.67
Prob>chi2	0.0000

Table 25: Heteroscedasticity Test for Open Economy

Modified Wald test for groupwise heteroskedasticity in fixed effect regression model	
H0: sigma(i)^2 = sigma^2 forall i	
chi2 (24)	3266.42
Prob>chi2	0.0000

Auto-Correlation test results are below 2. Null hypothesis which suggests that there is no auto correlation is rejected. It is plausible to say that there is auto correlation. Pesaran, Friedman and Frees test results also proves that sample is cross sectionally dependent.

Table 26: Auto-Correlation Tests for Open Economy

Modified Bhargava et al. Durbin-Watson	0.33709008
Baltagi-Wu LB	0.75391472

Table 27: Cross Sectional Dependency Tests for Open Economy

Pesaran's test = 5.560	Pr = 0.0000
Friedman's test = 29.918	Pr = 0. 0122
Critical values from Frees' Q distribution alpha = 0.10 : 0.2559 alpha = 0.05 : 0.3429 alpha = 0.01 : 0.5198	Frees' test = 2.729

Table 28: Correlation Matrix for All Economies excluding G7

e(V)	BRD	CAPITAL	FRD	_cons
BRD	1			
CAP	-0.4370	1		
FRD	-0.4411	0.4063	1	
_cons	-0.5687	-0.4894	0.0040	1

Table 29: Multi Collinearity Test

Variable	VIF	1/VIF
CAP	3.62	0.276535
BRD	1.46	0.683869
FRD	3.17	0.315805
Mean VIF	2.75	

7.3 Test Results for Unilateral Technology Transfer

Technology flow from G7 to countries with low labor productivity is examined in this section. These countries are presented below.[15] There is one-way (unilateral) transfer in this estimation rather than a bilateral one. The purpose of this investigation is to understand whether there is a spillover effect from major economies to countries with low productivity.

Table 30: Countries with Low Labor Productivity

Czech Republic	Korea	Portugal
Israel	Mexico	Slovenia
Hungary	Poland	Turkey

7.3.1 Closed Economy

Hausman Test result is lower than 0.05 probability. Fixed effect estimation will be done. Heteroscedasticity, auto-correlation and cross sectional dependency test results indicate that all problems exist in this sample.

Table 31: Hausman Test for Closed Economy

chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)	2415.05
Prob>chi2	0.0232

Table 32: Heteroscedasticity Test for Closed Economy

Modified Wald test for groupwise heteroskedasticity in fixed effect regression model	
H0: sigma(i)^2 = sigma^2 forall i	
chi2 (24)	201.25
Prob>chi2	0.0000

[15] Spain was in the sample but it is omitted because it is an outlier.

Table 33: Auto-Correlation Tests for Closed Economy

Modified Bhargava et al. Durbin-Watson	0.33698179
Baltagi-Wu LB	0.80357852

Table 34: Cross Sectional Dependency Tests for Closed Economy

Pesaran's test = 3.787	Pr = 0.0002
Friedman's test = 20.345	Pr = 0.0091
Critical values from Frees' Q distribution alpha = 0.10 : 0.2559 alpha = 0.05 : 0.3429 alpha = 0.01 : 0.5198	Frees' test = 1.658

7.3.2 Open Economy

The same sample consists of 9 countries is also tested as an open economy. Hausman Test showed that a fixed effect estimation method should be used. Modified Wals Test's P value equals to 0. It indicates that there is heteroscedasticity. Auto-Correlation Test results shows that there is auto correlation. All cross sectional dependency tests also prove that sample is cross sectional dependent.

Table 35: Hausman Test for Open Economy

chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)	378.64
Prob>chi2	0.0000

Table 36: Heteroscedasticity Test for Open Economy

Modified Wald test for groupwise heteroskedasticity in fixed effect regression model	
H0: sigma(i)^2 = sigma^2 forall i	
chi2 (24)	576.01
Prob>chi2	0.0000

Table 37: Auto-Correlation Tests for Open Economy

Modified Bhargava et al. Durbin-Watson	0.33148697
Baltagi-Wu LB	0.8039381

Table 38: Cross Sectional Dependency Tests for Open Economy

Pesaran's test = 2.650	Pr = 0.0081
Friedman's test = 18.115	Pr = 0.0204
Critical values from Frees' Q distribution alpha = 0.10 : 0.2559 alpha = 0.05 : 0.3429 alpha = 0.01 : 0.5198	Frees' test = 1.435

Table 39: Correlation Matrix for Unilateral Technology Transfer

e(V)	BRD	CAPITAL	FRD	_cons
BRD	1			
CAP	-0.2945	1		
FRD	-0.6592	0.3326	1	
_cons	-0.7569	-0.3778	0.2759	1

Table 40: Multi Collinearity Test

Variable	VIF	1/VIF
CAP	4.35	0.229630
BRD	2.87	0.347876
FRD	3.00	0.333590
Mean VIF	3.41	

7.4. Estimation Results

7.4.1 Labor Productivity Estimation for All Economies and G7

Samples demonstrate auto-correlation, heteroscedasticity and possible cross sectional dependency problem. In order to, control for these problems different types of estimation methods can be chosen. Parks-Kmenta, Beck-Katz and Driscoll- Kraay estimators are suitable, since all of them can control these three problems simultaneously. However, Parks-Kmenta and Beck-Katz would give biased results when number of cross sections are greater than the time period. On the other hand, Driscoll-Kraay gives more unbiased results with robust control for standard errors even when N□(→) ∞. That's why Driscoll-Kraay is a more suitable estimation method for the sample in this research. Driscoll-Kraay's method is the same as the Newey-West estimator which is used for time-series data. This method also controls for heteroscedasticity and autocorrelation. This method gives unbiased standard error estimations without taking the number of cross sections into consideration. Driscoll-Kraay estimation is implemented and the results are presented in the Table 39 and 40.

Table 41: Driscoll-Kraay F.E. Estimation - All Economies

VARIABLES	(1) LP	(2) LP
BRD	0.202***	0.194***
	(0.039)	(0.036)
CAP	0.161***	0.157***
	(0.040)	(0.035)
FRD		0.0214***
		(0.0057)
Observations	230	230
Number of groups	23	23
within R-squared	0.5605	0.5684

Std. Err. in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Effects of all explanatory variables on labor productivity can be observed. All variables are significant. Domestic sector R&D capital stock has the highest coefficient when foreign R&D capital has the lowest. Effect of domestic R&D is greater than the foreign R&D. All variables are also significant in G7 sample. Domestic R&D capital has the highest coefficient between seven major economies of the world. Foreign R&D capital's impact is the smallest. Effect of physical capital stock is lower than the domestic R&D capital. Comparison of two samples would lead to more intuitive results. It is possible to see that, both domestic and foreign R&D are more important between G7 countries comparing to the large sample. Coefficients of both explanatory variables are almost two times greater in the sample of G7 economies. When the seven major economies are investigated separated from the large sample, it can be seen that their own knowledge capital has a greater impact on labor productivity.

Table 42: Driscoll-Kraay F.E. Estimation - G7

VARIABLES	(1) LP	(2) LP
BRD	0.361***	0.319***
	(0.055)	(0.040)
CAP	0.151***	0.124***
	(0.023)	(0.017)
FRD		0.0543***
		(0.011)
Observations	70	70
Number of groups	7	7
within R-squared	0.5004	0.5589

Std. Err. in parentheses
*** p<0.01, ** p<0.05, * p<0.1

They are more efficient in research and development. The difference between effects of the foreign R&D capital is also an important result. It is shown that technology transfer between highly developed countries is greater than the spillover effect in a more heterogeneous sample. In the large sample, these 7 countries are measured along with many developing countries. There may be several reasons lead to this type of difference. It is a well-known fact that human capital is an important determinant of productivity. Countries which have a more educated labor force may be more advantageous in case of knowledge transfer. They can absorb the incoming information from the world efficiently. G7 countries may be able to absorb the knowledge which is transferred from each other easier than the countries in the large sample. Bilateral import weights is another important indicator. As an example; Canada, Italy, Japan and UK are very large importers of US' capital goods. They are all G7 seven countries. In the large sample, trade pattern is more diversified. It is plausible to say that, when a sample which consists of only highly developed countries is observed, knowledge capital (domestic and foreign) is a more important determinant of labor productivity. However, it is also proven that in a more heterogeneous sample with many countries there is positive effect of technology transfer on labor productivity via capital goods imports.

It can be said that productivity of labor increases by two major channels; research and development and physical capital. First, one may also work through two different channels. Successful innovation projects directly affects labor and workers learn to do a job more efficiently. This new knowledge may be a result of either domestic efforts or transfer of knowledge from foreign economies. It is shown that both have positive effects. However, countries' own R&D efforts is always more effective than information transfer from the world. Secondly, inventions/innovations lead to creation of improved equipment which also advances labor productivity indirectly. Labor is affected by the innovations which are implemented on physical capital. It is also important that physical capital directly affects the labor in a significant and positive way. Labor works more efficiently as the amount of capital they can use increase. Physical capital stock is a crucial element of production since it compensates for the marginal diminishing returns of labor.

Total Factor Productivity is commonly used in the literature as a measure of productivity in the economy. It is proven that one of the major determinants of TFP is research and development capital (knowledge capital). In this research it is shown that both domestic and foreign R&D capital stock have positive and significant effects on labor productivity. One of the arguments in this research is as follows: Investigating the effect of knowledge on TFP, is actually looking at the indirect effects of R&D on labor productivity.

In the end, technological advancements which increase TFP are learned by workers. Either they have better equipment or they directly learn how to produce more efficiently, as a result labor is the ultimate factor which becomes more productive. That's why labor productivity is chosen as a dependent variable rather than TFP in this research. The main purpose is to show that the knowledge capital has an impact directly on labor. In a traditional production function, TFP is presented as a multiplier for the other factors of production[16]. In the literature, it is repetitively shown that expansion of the knowledge capital of countries alters the TFP directly. Then, it can be assumed that the rise in TFP may have a multiplier effect on labor or capital. However, by looking at the results in this research, it can be said that technological improvements might have direct impact on labor productivity.

7.4.2 Labor Productivity Estimation for All Economies Excluding G7

Driscoll-Kraay fixed effect estimation method is used again. Because sample is heteroscedastic, auto-correlated and cross sectional dependent. There are 16 countries and 10 years. Domestic R&D capital is the most effective determinant of productivity. It is proved that externalities exist between these economies too. Even though major world economies are not included, technology transfer occurs between other advanced and developing countries. However, coefficient of foreign R&D capital is significantly lower than the large sample with G7 economies. It is plausible to say that even though there is spillover effect without the seven most advanced countries in the world, the effect is lower.

Table 43: Driscoll-Kraay F.E. Estimation – G7 Excluded

VARIABLES	(1) LP	(2) LP
BRD	0.192***	0.162***
	(0.037)	(0.033)
CAP	0.167***	0.158***
	(0.042)	(0.032)
FRD		0.0288***
		(0.0092)
Observations	160	160
Number of groups	16	16
within R-squared	0.5734	0.5894

Std. Err. in parentheses
*** p<0.01, ** p<0.05, * p<0

[16] A detailed calculation of TFP is presented in section 1.2.2.

7.4.3 Labor Productivity Estimation for Unilateral Technology Transfer

Driscoll-Kraay estimation results, shows that domestic R&D capital stock and physical capital are significant. Their effects are positive and physical capital is a more effective determinant. This particular result differs from the other sample estimations. Because coefficient of R&D capital is lower than the fixed capital. It is plausible to say that since countries in the sample are not advanced, structure of the industries are not consisting of high technology production. Labor productivity of countries in this sample is below average in the largest sample consists of 23 economies.

Open economy results also differentiates from the previous sample estimations. Foreign R&D capital stock turns out to be insignificant. It is possible to say that countries which are not "developed enough" to absorb the influx of information from countries which are highly advanced, cannot use this externality to increase their productivity. It should be noted that this result is valid for a "unilateral technology transfer". In this sample, only the information incoming from G7 to countries with low productivity is examined. However, the large sample with 23 countries is constructed using bilateral trade matrix and the foreign R&D capital stock turned out to be significant and positive. The difference between results could also be arise because of the number of countries in the two samples.

Table 44: Driscoll-Kraay F.E. Estimation – Unilateral Technology Transfer

VARIABLES	(1) LP	(2) LP
BRD	0.191***	0.181***
	(0.039)	(0.037)
CAP	0.230***	0.234***
	(0.052)	(0.050)
FRD		0.0204
		(0.010)
Observations	90	90
Number of groups	9	9
within R-squared	0.6738	0.6795

Std. Err. in parentheses
*** p<0.01, ** p<0.05, * p<0.1

8 CONCLUSION

This research concluded that domestic, foreign knowledge capital and physical capital have significant and positive effects on labor productivity in different samples when there is bilateral technology transfer. First sample consists of 23 countries between 2002 and 2011. The results showed that domestic R&D is more effective than the externalities originated from foreign countries. Only G7 economies are estimated in the second sample. Both domestic and foreign R&D capital stock have higher coefficients in this case. Physical capital is also taken into account in order to capture the marginal diminishing returns. This variable has also positive impact on productivity.

Endogenous growth theory with spillover effects have many notions which are proven correct in this research. Knowledge capital is a significant explanatory variable for productivity. Foreign R&D capital stock which measures the externalities globally is important and effective for all economies in the sample. These two determinants are more important for a homogeneous sample which consists of seven highly developed countries.

Quality ladder model of Grossman and Helpman (1991) was presented as a theoretical model in this thesis. It is chosen because Grossman and Helpman derived a model which is explaining how innovation efforts and R&D market functions in a more realistic way.

Total factor productivity is generally used as a proxy for productivity in the literature. However labor productivity is chosen as dependent variable in this thesis. Results are not conflicting with the main literature. Effects of the variables which are significant for TFP demonstrates similar outcome for labor productivity. It is also proven that capital import is an essential channel of knowledge transfer. This results confirm the findings of Coe, Helpman and Hoffmaister (1997) and Xu and Wang (1999).

Four samples are estimated for different cases; closed and open economy. In the first situation, spillover effects are not taken into consideration. Effect of this determinant is captured in the latter case. It is shown that even though impact of knowledge produced within the countries declines when externalities come into picture, it is still more effective than the R&D capital comes from the outside world.

Finally, this thesis concludes that domestic and foreign R&D capital stock along with the physical capital stock are significant and major determinants of labor productivity in three different samples. Knowledge capital is more effective in a small sample which consists of seven developed economies. It is also confirmed that capital goods import is an important transmission mechanism for technology transfer.

References

Agnieszka Gehringer, I. M.-Z. (2013). The Determinants of Total Factor Productivity in the EU: Insights from Sectoral Data and Common Dynamic Processes. *Working Paper EcoMod2013*.

B. H Baltagi, P. X. (1999). Unequally spaced panel data regression with AR(1) disturbances. *Econometric Theory 15*, 814-823.

Bin Xu, J. W. (1999). Capital Goods Trade and R&D Spillovers in the OECD. *The Canadian Journal of Economics*, 1258-1274.

Bozkurt, C. (2015). R&D Expenditures and Economic Growth Relationship in Turkey. *International Jourmal of Economics and Financial Issues*, 188-198.

Bruno van Pottelsberghe de la Potterie, F. L. (2001). Does Foreign Direct Investment Transfer Technology Across Borders? *The Review of Economics and Statistics*, 490-497.

Coe, D. T., Helpman, E., & Hoffmaister, W. (2008). International R&D Spillovers and Institutions. *NBER Working Paper Series, 14069*.

David T. Coe, E. H. (1993). International R&D Spillovers. *Working Paper International Bureau of Economic Research*.

David T. Coe, E. H. (1995). International R&D Spillovers. *European Economic Review*, 859 - 887.

David T. Coe, E. H. (1997). North-South R&D Spillovers. *The Economic Journal*, 134-149.

David T. Coe, E. H. (2008). International R&D Spillovers and Institutions. *IMF Working Paper*.

Ding Weina, Z. X. (2014). Knowledge Spillover Effects of International Trade of OECD Countries. *International Conference on Logistics Engineering, Management and Computer Science.* Atlantis Press.

Erkan Erdil, S. M. (2013). Do R&D Expenditures Matter for Labor Productivity in OECD Countries? An Unresolved Question. *H.Ü. İktisadi ve İdari Bilimler Fakültesi Dergisi*, 71-82.

Frees, E. W. (1995). Assessing cross-sectional correlation in panel data. *Journal of Econometrics 69*, 393-414.

Friedman, M. (1937). The use of ranks to avoid the assumption of normality implicit in the analysis of variance. *Journal of the American Statistical Association 32*, 675-701.

Gene M. Grossman, E. H. (1990). Trade, Innovation and Growth. *The American Economic Review*, 86-91.

Gene M. Grossman, E. H. (1991). Quality Ladder in the Theory of Growth. *The Review of Economic Studies*, 43-61.

Greene, W. H. (2000). *Econometric Analysis.*

Hasan Vergil, M. S. (2013). An Investigation of the Relationship between Foreign Trade and Economic Growth in terms of Knowledge Transfer: The Case of Turkey. *Business and Economics Research Journal*, 59-76.

Hausman, J. A. (1978). Specification tests in econometrics. *Econometrica*, 1251-1271.

Helpman, G. M. (1991). Quality Ladders in the Theory of Growth. *The Review of Economic Studies*, 43-61.

J. Driscoll, A. C. (1998). Consistent covariance matrix estimation with spatially dependent data. *Review of Economics and Statistics*, 549-560.

Jürgen Bitzer, M. K. (2008). Does Foreign Direct Investment Transfer Technology Across Borders? *Economic Letters 100*, 355-358.

Lichtenberg, F. R. (1992). R&D Investment and International Productivity Differences. *NBER Working Paper Series*.

M. Henry, R. K. (2009). Trade, Technology Transfer and National Efficiency in Developing Countries. *European Economic Review*, 237-254.

Meçik, O. (2014). The Effects of R&D Expenditure on Economic Development. *The Journal of International Social Research*.

Meçik, O. (2015). The Impact of Information and Communication Technologies on Labor Productivity in OECD Countries. *Journal of Management and Economics Research*, 74-84.

Merter Akıncı, H. S. (2013). The Relationship Between R&D Expenditures and Economic Growth The Case of Turkey, 1990-2011. *The Journal of International Social Research*.

Michel Beine, F. D. (2001). Brain drain and economic growth: theory and evidence. *Journal of Development Economics*, 275-289.

Murat Can Genç, Y. A. (2010). The Relationship Between R&D Expenditure and Economic Growth: Panel Data Analysis. *The Journal of Knowledge and Knowledge Management*.

N. Beck, J. K. (1996). Nuisance vs. Substance: Specifiying and Estimating Time Series Cross Section Models. *Poltical Analysis 6*, 1-36.

Parker, J. (2011). *Macroeconomic Theory.*

Parks, R. W. (1966). Efficient Estimation of a System of Regression Equation When Distrubance are Both Serially and Contemporaneously Correlated. *Journal of the American Statistical Association 62*, 500-509.

Pesaran, M. H. (2004). General diagnostic tests for cross section dependence in panels. *Cambridge Working Papers in Economics No. 0435*.

Philippe Aghion, P. H. (1992). A Model of Growth Through Creative Destruction. *Econometrica*, 323-351.

Romer, P. M. (1986). Increasing Returns and Long-Run Growth. *Journal of Political Economy*, 1002-1037.

Romer, P. M. (1990). Endogenous Technological Change. *Journal of Political Economy*.

Solow, R. M. (1956). A Contribution to the Theory of Economic Growth. *The Quarterly Journal of Economics*, 65-94.

Appendix A

In this thesis, domestic R&D capital stocks of the countries are calculated using the perpetual inventory method. Capital stock for the initial year is calculated in the first equation. E_0 is the R&D expenditure in the first year of the data. It is the data for 2002 in this case. g stands for the average annual logarithmic growth of R&D expenditures in all years and δ is the depreciation rate which is 10%.[17]

$$R_0 = E_0 / (g + \delta)$$

In the second equation, R_{t-1} stands for the capital stock in year t-1 and E_t denotes the expenditure on R&D in year t. (1- δ) represents the remaining capital stock after the depreciation rate.

$$R_t = (1 - \delta) R_{t-1} + E_t$$

It should be noted that R_t for each year is shown as BRD in the thesis which stands for Domestic R&D capital stock. Flow variables such as R&D expenditure can be turned into stock variables by using perpetual inventory method.

[17]Deprecation rate is chosen as 10% based on M.Henry, R.Kneller and C.Milner (2009). It is generally determined as 5%, 10% or 15% in the literature.

Appendix B

Labor is also used as an explanatory variable in the model. Because it is one of the two important factors of production along with the physical capital. However it is omitted later because of the multicollinearity problem. Labor is measured as number of people who are employed and "EMP" stands for it in Table 45. It can be seen that variance inflation factor (VIF) is extremely high in all domestic variables.

All values are significantly higher than 10. Highest VIF value belongs to employment. Both samples demonstrate multicollinearity problem. VIF value for labor is higher in G7 sample. Mean values are also very high. Only variable with a VIF value smaller than 10 is foreign R&D capital stock. As a result models are estimated without employment.

Table 45: Multi Collinearity Test

	G7		All Economies	
Variable	VIF	1/VIF	VIF	1/VIF
CAP	25.20	0.039678	25.93	0.038562
EMP	62.06	0.016114	18.67	0.053564
BRD	13.64	0.073323	4.31	0.231865
FRD	6.79	0.147214	1.54	0.648267
Mean VIF	26.92		12.61	

Appendix C

Data for each country in 2011 are presented in this section. All data are in US million dollars with 2010 as base year. Data for only one year is shown since there is a large sample which consists of 230 observations. Values are in logarithmic forms in the tables. Trade matrix for capital goods are in Table 47. Importer countries are shown in the first column.

Table 46: Data (Million US Dollars in 2011)

Country	BRD	FRD	LP	CAP
Australia	4.930303	2.652930	1.946396	5.444249
Austria	4.701843	2.726453	1.936831	4.908068
Belgium	4.700602	2.893567	1.981384	4.987976
Canada	5.121478	3.226576	1.896017	5.52542
Czech Republic	4.233468	2.749579	1.758343	4.888009
Finland	4.656277	2.445455	1.922995	4.670333
France	5.45912	2.535061	1.943643	5.720773
Germany	5.713295	2.498232	1.90759	5.829429
Spain	4.918249	1.933044	1.892024	5.509511
Hungary	3.958763	2.713752	1.739192	4.6372
Israel	4.770438	3.232212	1.818141	4.672375
Italy	5.04986	2.530924	1.921062	5.604689
Japan	5.996762	2.082887	1.825282	5.942387
Korea	5.395854	3.008571	1.808715	5.665515
Mexico	4.373826	2.370229	1.583701	5.596225
Netherlands	4.782784	2.237301	1.931561	5.190353
Norway	4.336335	2.754359	2.042647	4.80339
Poland	3.988352	1.809222	1.732158	5.243797
Portugal	4.052239	3.147016	1.767211	4.70894
Slovenia	3.686051	3.664885	1.779091	4.059181
Turkey	4.329622	2.246300	1.722121	5.416542
UK	5.345007	2.534511	1.893089	5.565376
United States	6.389769	1.941986	2.029238	6.445695

Table 47: Bilateral Capital Goods Import Shares (Million US Dollars in 2011)

Importer	Australia	Austria	Belgium	Canada	Czech	Finland	France	Germany	Spain	Hungary	Israel	Italy
Australia	0	0.007488	0.014091	0.015677	0.004524	0.010984	0.027559	0.14071	0.007419	0.004215	0.038832	0.251083
Austria	0.000721	0	0.02144	0.003804	0.058422	0.005849	0.047392	0.522749	0.035676	0.001662	0.07584	0.043879
Belgium	0.000338	0.008021	0	0.004297	0.028143	0.002733	0.163748	0.269821	0.010418	0.003115	0.050617	0.072012
Canada	0.001621	0.003257	0.00289	0	0.001133	0.002805	0.012972	0.053258	0.001667	0.001702	0.012531	0.070473
Czech	0.000427	0.03438	0.013764	0.00211	0	0.004602	0.052387	0.441894	0.035753	0.001442	0.05167	0.054873
Finland	0.001967	0.020444	0.049607	0.01184	0.039979	0	0.054459	0.364446	0.011299	0.004873	0.060953	0.0233
France	0.000645	0.013866	0.039006	0.008766	0.034406	0.004411	0	0.348066	0.01704	0.00221	0.095646	0.051085
Germany	0.000861	0.069008	0.033077	0.007486	0.089768	0.007336	0.147079	0	0.057828	0.002217	0.077145	0.082878
Spain	0.000232	0.053911	0.016335	0.021111	0.039738	0.00317	0.041365	0.431229	0	0.001025	0.047966	0.042304
Hungary	0.000796	0.004755	0.036042	0.007357	0.017583	0.007018	0.042989	0.14706	0.009602	0	0.069221	0.124609
Israel	0.000564	0.019371	0.036927	0.004727	0.02942	0.00635	0.114944	0.352302	0.018175	0.002185	0	0.036059
Italy	0.002275	0.009374	0.010958	0.01375	0.004945	0.006681	0.039935	0.185216	0.007264	0.005417	0.03006	0
Japan	0.005444	0.0098	0.003549	0.007232	0.004547	0.007996	0.046672	0.151123	0.004752	0.004066	0.023096	0.380326
Korea	0.001175	0.003604	0.002292	0.035281	0.003634	0.002186	0.011733	0.078075	0.0034	0.00218	0.020655	0.11102
Mexico	0.000971	0.008883	0.101952	0.005219	0.063106	0.011722	0.058998	0.28112	0.01976	0.004765	0.033791	0.111378
Netherlands	0.001131	0.012002	0.022183	0.006684	0.025141	0.038311	0.056436	0.265142	0.010709	0.00194	0.04195	0.060246
Norway	0.000896	0.030781	0.023341	0.002886	0.056554	0.011628	0.0636	0.347977	0.03279	0.002367	0.108954	0.043198
Poland	0.000414	0.007756	0.021238	0.001206	0.023614	0.004902	0.101015	0.304761	0.015769	0.001111	0.076363	0.032966
Portugal	0.000935	0.018138	0.015423	0.00852	0.037562	0.023876	0.042426	0.255959	0.022279	0.002772	0.076654	0.151281
Slovenia	0.000847	0.016764	0.027435	0.004813	0.030814	0.004139	0.211697	0.279311	0.023266	0.003769	0.092206	0.044238
Turkey	0.000498	0.013114	0.018887	0.003937	0.024167	0.009736	0.094599	0.274058	0.018268	0.00418	0.116003	0.060755
UK	0.001915	0.012914	0.062332	0.007688	0.02984	0.005773	0.07536	0.30368	0.02574	0.002867	0.048244	0.082845
US	0.002706	0.009639	0.007246	0.170101	0.003678	0.002683	0.030963	0.116799	0.003947	0.007108	0.024537	0.195725

Japan	Korea	Mexico	Netherlands	Norway	Poland	Portugal	Slovenia	Turkey	UK	US	
0.08395	0.020156	0.009083	0.005177	0.003885	0.001165	0.000142	0.012965	0.002908	0.05199	0.285998	1
0.014267	0.004542	0.031354	0.000964	0.017292	0.008853	0.000422	0.027849	0.008838	0.026267	0.041919	1
0.01238	0.006714	0.139487	0.002392	0.021742	0.006943	0.000453	0.036191	0.024201	0.066938	0.069298	1
0.03257	0.118239	0.003034	0.002333	0.003773	0.000427	0.000227	0.001802	0.001235	0.02358	0.64847	1
0.052856	0.00731	0.063102	0.001004	0.063191	0.004792	0.007631	0.028972	0.011534	0.02831	0.037995	1
0.032075	0.004437	0.096969	0.015657	0.02395	0.001767	0.014143	0.025611	0.009114	0.073396	0.059715	1
0.019777	0.004441	0.030906	0.001408	0.027527	0.012358	0.001018	0.098242	0.02595	0.059403	0.103825	1
0.038655	0.015838	0.058178	0.001961	0.053408	0.00796	0.001389	0.048667	0.018034	0.075582	0.105645	1
0.061231	0.011982	0.061794	0.000505	0.065051	0.003119	0.004017	0.018082	0.006805	0.028868	0.040158	1
0.077025	0.006807	0.101487	0.000803	0.004758	0.003804	0.001336	0.026495	0.041815	0.051101	0.217538	1
0.023691	0.00554	0.086992	0.000876	0.055391	0.005562	0.000549	0.069362	0.027421	0.05678	0.046813	1
0.212595	0.021564	0.027371	0.004115	0.004191	0.003892	0.000108	0.005015	0.00104	0.038392	0.365842	1
0	0.009147	0.041214	0.019668	0.002744	0.000553	0.001408	0.002837	0.003617	0.018812	0.251398	1
0.099513	0	0.002211	0.000356	0.002507	0.001094	0.000117	0.016477	0.001028	0.008321	0.59314	1
0.018845	0.015061	0	0.004288	0.028886	0.002335	0.001071	0.02943	0.005671	0.07725	0.115497	1
0.098761	0.005289	0.045106	0	0.044688	0.002371	0.002871	0.044252	0.011296	0.091327	0.112164	1
0.049275	0.004695	0.058738	0.018043	0	0.005233	0.009925	0.030472	0.01932	0.036606	0.042719	1
0.012261	0.002227	0.028228	0.000357	0.014072	0	0.000203	0.257288	0.012493	0.044054	0.037701	1
0.108445	0.006332	0.02408	0.007901	0.027789	0.001966	0	0.017656	0.02433	0.04928	0.076395	1
0.0195	0.004104	0.049147	0.001729	0.033465	0.035423	0.000252	0	0.01715	0.059032	0.040898	1
0.075769	0.008809	0.019343	0.001467	0.047227	0.004069	0.001058	0.058467	0	0.053114	0.092475	1
0.020349	0.007903	0.082687	0.00424	0.03032	0.006324	0.000284	0.043897	0.023794	0	0.121007	1
0.080601	0.284678	0.011142	0.001556	0.003709	0.001132	0.000664	0.004095	0.003002	0.034289	0	1

Appendix D

Figure 7: Scatter Plot for All Economies

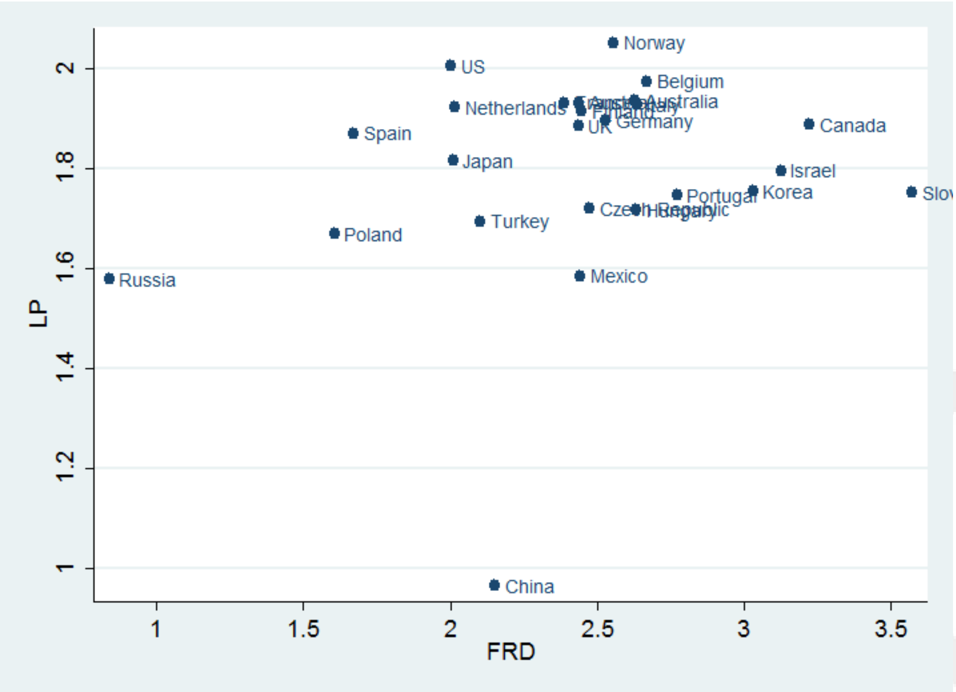


Figure 8: Scatter Plot for Countries with Low Productivity (Unilateral Technology Transfer)