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The Schengen Area and Technology Diffusion

The effect of Schengen on industry specific total factor productivity growth rates

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Abstract

The technological level of a country is known to have a significant impact on the economic growth of the region. Technology specifically is what drives the progression of productivity. The concept of technology diffusion addresses the phenomenon of countries adopting and using new technology. This paper aims to address the issue of whether the Schengen Area has influenced the technology diffusion within member states and if so, in what way. The Total Factor Productivity (TFP) level of a country is used as a measure of the technological level. Previous studies have highlighted the importance of the TFP gap as well as the TFP growth rate at the frontier with regards to technology diffusion. Panel data is collected and empirically studied using methods established in previous studies. Apart from the two mentioned variables, the roles of Information and Communication Technologies (ICT), Research and Development (R&D), and high-skilled human capital are also considered in order to give a more holistic view of the determinants of the diffusion of technology. The results in this paper confirm to a large extent the work of previous studies. Both the TFP gap and the TFP growth rate at the frontier are found to positively correlate with the TFP growth rate of a country. The impact of the Schengen Area on technology diffusion is however less conclusive. The results indicate that the Area to some extent may affect the diffusion of technologies. It is therefore unwise to disregard Schengen and the role it plays. Further research is recommendable.

Keywords: Schengen, Technology diffusion, Total Factor Productivity, Economic growth

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1. Introduction

It is widely accepted among economists that sustained economic growth is largely driven by technological progress (Jones & Vollrath, 2013). The technological level of a region is therefore in large respects a determinant of the potential for economic growth for the country in question. This causes the level of technology to be a helpful tool when identifying and explaining the world's distribution of income (Keller, 2001).

The level of technology in a country is however not solely dependent on what happens within its borders. Productivity growth due to technical change originates largely abroad (Eaton & Kortum, 1999). It is through the process of technology diffusion[1] that a country can increase its level of technology and in turn its growth potential. The rate of diffusion is mainly affected by the technological level abroad in addition to the ability of the country to adopt the technology beyond its borders. The highest technological level abroad is often named the technological frontier and is composed of the country with the highest technological level. Empirically, the ability of a country to adopt new technology corresponds to the gap between the technological level of the country at the frontier and the host country.

The Schengen Area is an agreement between several European nations[2] regarding a free travel area between the member countries. The Area is commonly characterized by a lack of border controls. Internationally Schengen functions as a single country with a common visa policy and mutual borders. Four new states[3] are expected to join the agreement in mid-2016, increasing Schengen's members to 30 countries. The lack of border controls has largely simplified the movement of both people and goods.

The aim of this paper is to identify whether the Schengen Area has facilitated technology diffusion across its member states and if so to what degree. This paper thus hopes to expand the awareness of the effect that the Schengen Area has on the region. In turn, a deeper understanding of Schengen allows the public and elected officials in the member states to make informed decisions about the future of the Area. The papers aim is justified by the fact that regulation, such as restrictions to labour and product markets, largely affect a country's productivity performance (Havik, et al., 2008).

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[1] Also referred to as technology transfer in several research papers.

[2] Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, and Switzerland.

[3] Bulgaria, Croatia, Cyprus, and Romania.

As technology itself is a difficult factor to measure, Total Factor Productivity (TFP)[4] is alternatively used to assess a country's technological level. In growth accounting TFP is often represented by the Solow residual (Fregert & Jonung, 2013).

This paper heavily relies on previous empirical applications of the EU KLEMS and the Groningen Growth and Development Centre (GGDC) databases. The methods from previous research are in part replicated but also complemented with a variable that encompasses the Schengen Area. This strategy ensures sophisticated methods while adding a new dimension to the results. Panel data is used to regress the TFP growth rate on the TFP gap and the TFP level at the frontier along with a dummy variable for the Schengen members. This basic regression is then expanded to include further control variables in the form of Information and Communication Technology (ICT) compensation, Research and Development (R&D) expenditure, as well as high-skilled human capital.

As with previous literature, this paper identifies a significant relationship between both the TFP gap and the TFP level at the frontier with TFP growth rates. A larger TFP gap between the country at the frontier and the catching-up economies correlates with a higher TFP growth rate for the country in question. This is mainly due to the catching-up effect. Similarly, the TFP level at the frontier is also positively correlated with a country's TFP growth rate. This confirms to a certain extent the spillover effect. The roles and significances of the supplementary control variables vary as they also have done in previous studies. Additionally, the results identify a possible significant relationship between Schengen membership and TFP growth rates.

The remainder of this paper is organized as follows. Section 2 presents The Schengen Area and covers its purpose and effects on mainly the labour market and trade. Section 3 reviews the theoretical framework required for the empirical study. Previous research within this topic is examined in section 4. Section 5 and 6 discuss the data used in this paper and presents the method respectively. An empirical analysis is carried out in section 7 and the results are discussed subsequently in section 8. Concluding remarks are offered in section 9 as wells as a discussion of further research. The paper ends with a list of references in section 10 and an appendix.

[4] Regarded as the same as multifactor productivity in this paper.

2. The Schengen Area

2.1. Background and Purpose

The Schengen Agreement was first signed in 1985 by seven EU states (European Commission, 2016). The Area itself was however not implemented until 1995. The main implication of the Schengen Area has been abolishing border controls within the region. A tightened external border has instead replaced the internal borders of each member country. This is done by for example instigating a common set of rules along the external border. However, Schengen also includes a common set of rules regarding visa application and right of asylum (EUR-Lex, 2009). The Agreement has also been incorporated into the body of EU law (Ademmer, et al., 2015).

The main purpose of the Schengen Area is to promote the free movement of people within its borders. Specifically, the Area facilitates citizens to move and work freely in the member states. The Agreement was, and is, a crucial component in creating a large-scale international labour market (Davis & Gift, 2014). Today the Area includes 26 member states of which four are non-EU countries[5].

In late 2015 the Schengen Area was strained due to the migrant crisis stimulating a vast influx of refugees into Europe. This resulted in several countries temporarily reinstating border controls. The long run effect of the migrant crisis on the Schengen Area is however yet to be determined. As of the writing of this paper however several countries have implemented temporary border controls[6] (European Commission, 2016).

2.2. Effects

The Schengen Agreement has significantly helped integrate both the labour and goods market among its member countries. Recent figures show that about 1.7 million individuals in the Schengen Area work in a different country to where they live (Wolff, 2016). Whether this figure has been solely affected by abandoning border controls is however difficult to say and exceeds the scope of this paper. What is important to note though is that the Schengen Area directly affects a substantial amount of labourers and perhaps also their productivity as workers.

Member states have also seen a rise in cross-country commuting after the Schengen Agreement was signed (The Economist, 2016). Malmö, in southern Sweden, and

[5] Iceland, Norway, Switzerland, and Liechtenstein.
[6] These are Austria, Denmark, France, Germany, Norway, and Sweden.

Copenhagen, the capital of Denmark, have in one sense become one large city. Of course, aided by the bridge connecting the two, commuters also benefit from the lack of border controls, which reduce commuting time by around 30 minutes both ways. Switzerland, offering relatively high wages, has seen an influx of Italian workers from Northern Italy. Commissioned by the EU, Nerb, et al. (2009) identified that around 6 per cent of employees in Switzerland and a noteworthy 43 per cent in Luxembourg reside in another country. Thus, Schengen benefits border regions by connecting labour markets and helps smooth income disparities (Ademmer, et al., 2015).

The Schengen Agreement has not only facilitated the flow of people, but also the flow of goods within the Area. Every year about 57 million trucks, carrying €2.8 trillion worth of goods, cross the internal borders of the EU (The Economist, 2016). Exporters are perhaps most affected by the lack of border controls as over a third of road-freight traffic in Schengen crosses a border. By abolishing controls, bottlenecking has reduced and truck drivers can spend their time more effectively. It can also be stated to be one of the key benefits for businesses as goods and services travel across borders at a greater speed (Heinze, 2015). This in turn has the possibility of making these goods and services more competitive compared to non-Schengen ones.

An overview of the effects of Schengen is supplied above. A more complete review of the recent research concerning the Area is given in section 4.

3. Theoretical Framework

3.1. Technology

A first step in order to better grasp the remainder of this paper is to understand what technology is. Jones and Vollrath (2013, p. 80) identify technology as the way inputs are converted into output in the production process. Further, the authors classify ideas as being the building blocks of technological advancement. Ideas in themselves differ from other economic goods as they are non-rivalrous. In theory, this means that once an idea has been created, other individuals, firms, or countries can take part of it and use it to improve their technological level. In practice however, ideas are many times excludable (Jones & Vollrath, 2013, p. 81).

Excludability is realized by the use of patent or copyright laws, limiting the use of the idea in question. These laws are implemented in order to protect the innovator and ensure that profits can be made from new ideas. Without this incentive, many innovations would possibly never have surfaced. It is up to lawmakers to ensure that patents are not exploited to the detriment of the public. Pepall, et al. (2014, p. 578-584) review the implications of patents with varying length and breadth. The length of a patent refers to the amount of years an innovator holds exclusive rights to their idea. Patent duration varies among countries and industries. On the other hand, patent breadth deals with the necessary amount of divergence a new idea must hold in order to be considered new and be granted protection. The authors identify that optimal patents are those that find a balance between the ability for the innovator to earn profits as well as the benefit received to the consumers once the patent expires and competition emerges. The theoretical calculations of optimal patents exceed the scope of this paper however and will not be treated.

Due to its nature, technology itself is a difficult variable to measure. Studies that seek to understand how the technological level of an economy affects a dependent variable make use of several different measurements. Some studies resort to the amount of patents introduced per year while others focus on the share of GDP that is spent on R&D. Additionally, researchers also use the number of scientists and engineers employed within a country as a determinant of technological level. This paper is however interested in identifying whether the Schengen Area has affected the technological level, which is why TFP is used as a measure of technology. This is further explained in section 3.3.

3.2. Endogenous Growth Theory

Neoclassical growth theory views technological growth as exogenous. In other words, as something that is decided outside of the model. The well-established Solow growth model offers a theoretical framework for explaining long-run economic growth[7]. Robert Solow (1956) identified in his hallmark article that technological growth is the key driver for long-run growth in income per capita in an economy. The drawback of exogenous models however are that they leave the source of the technological change unanswered. This paper will because of this instead rely on endogenous growth theories rather than exogenous ones. In other words this paper will rely on technology being something that can be affected within the model.

3.2.1. The Romer Model

Romer (1990) developed the endogenous growth model, which granted innovators monopolistic rights for their innovations. This in turn led to the incorporation of researches

[7] See Jones and Vollrath (2013)

seeking to make profits within the model. The Romer model is illustrated in the following production function (Jones & Vollrath, 2013, p.99):

$$Y = K^{\alpha}(AL_Y)^{1-\alpha}$$

This Cobb-Douglas function includes the capital stock, labour engaged in the production of goods and services, and the stock of ideas denoted as K, L_Y, and A respectively. The parameter α indicates the shares divided between the inputs and is regarded to be around 1/3. The combination of inputs is used to produce output, Y, typically referred to as GDP. The main difference between the original Solow model and the developed Romer model is the introduction of the variable A, in other words technology. This in turn enables increasing returns to scale rather than constant returns as in previous models (Jones & Vollrath, 2013, p. 99). Increasing returns to scale arise due to the non-rivalrous nature of ideas previously discussed.

The accumulation of capital and labour in the Romer model are identical to the ones in the Solow model and will only briefly be reviewed here. Capital accumulates according to the following equation (Jones & Vollrath, 2013, p. 100):

$$\dot{K} = s_k Y - \delta K$$

Here, s_k equals the saving rate of the population and δ equals the depreciation rate of capital. Hence, capital forms due to the forgone consumption, also equal to investments made, of individuals minus the depreciation of the existing capital stock. Labour growth is treated as the population growth of an economy, which grows exponentially at a constant and endogenous rate, n. The accumulation of labour is shown in the following equation (*ibid*):

$$\frac{\dot{L}}{L} = n$$

The difference between the exogenous and endogenous models is that the growth of technology in the latter is explained. The basic production function for the change in the stock of technology is (*ibid*):

$$\dot{A} = \bar{\theta} L_A$$

The equation states that the number of new ideas produced equals the number of people attempting to discover new ideas multiplied by the rate at which the new ideas are discovered. Furthermore, the rate at which new ideas are conceived depends on how existing ideas affect new ones. The relationship between new and old ideas is given by the following equation (Jones & Vollrath, 2013, p. 101):

$$\bar{\theta} = \theta A^{\phi}$$

Here, the parameter ϕ resembles to what degree new ideas are built on old ones. If $\phi>1$, past inventions alleviate the productivity of current researches and $\bar{\theta}$ would be an increasing function of A. On the other hand, $\phi<1$ implies that future innovations are harder to discover meaning that $\bar{\theta}$ would be a decreasing function of A. A third alternative arises if $\phi=0$, asserting that the productivity of researches is independent of the previous knowledge base (*ibid*). By acknowledging the previous equation as well as the possibility of a decreasing rate of return for people engaged in research a new production function for the growth in technology arises (*ibid*):

$$\dot{A} = \theta A^{\phi} L_A^{\lambda}$$

3.2.2. The Schumpeter Model

A more recent growth theory, the Schumpeterian view, has emphasized the importance of innovations as a key driver for growth (Jones & Vollrath, 2013). As innovations are particularly present in advanced economies the theory is most relevant to economies at, or close, to the technology frontier (Havik, et al., 2008). New innovations both replace existing, inferior, technology and catalyse the adoption of newer technology. The rate at which new innovations come to be depends mainly on the resources devoted to innovating[8] and on the depth of existing knowledge.

The main alteration in the production function in the Schumpeter model compared to the Romer model is that the technology variable is considered to be the latest version of the technology in question (Jones & Vollrath, 2013, p. 120):

$$Y = K^{\alpha}(A_i L_Y)^{1-\alpha}$$

The index i represents the latest form of technology. Hence, the Schumpeter model advocates technological development in steps rather than a continuous development as in the Romer model. This difference causes the growth of technology to be determined by two factors. The growth will be affected by both the size of the innovation and by the probability that an innovation actually occurs.

The theoretical calculations of the model will not be reviewed further as it exceeds the purpose of this paper. Important to note is however that countries that do not themselves innovate rely instead on their capability of adopting new technology. For these countries it is instead the rate of technology diffusion that corresponds to long run economic growth. A review of this model is offered in section 3.4.

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[8] For example, R&D and human capital.

3.3. Total Factor Productivity as an Indicator of Technological Level

TFP is commonly referred to as the part of output not covered by the inputs used in production (Comin, 2006). Because of its nature it is able to constitute for the efficiency of the inputs used in production. The inputs, as well as their efficiency have been summarized in the previous production function above. TFP acts as a replacement for technology and is represented by A in the production function (Fregert & Jonung, 2013, p. 152). In general terms, the higher the TFP level is, A, the more output is produced per unit of input. Furthermore, the change in TFP can be said to be the growth in technology.

TFP is not commonly something that can be measured and collected but is instead calculated from the above production function. Because of this, it is usually referred to as the Solow Residual (Fregert & Jonung, 2013, p. 153). The first step in yielding the residual is to apply changes to each variable in the original production function (*ibid)*:

$$\dot{Y} = \dot{A} + \alpha\dot{K} + (1 - \alpha)\dot{L}$$

The newly formed equation is then rewritten to capture the change in TFP as a product of the change in GDP minus the change in inputs (Fregert & Jonung, 2013, p. 154):

$$\dot{A} = \dot{Y} - \left[\alpha\dot{K} + (1 - \alpha)\dot{L}\right]$$

The data sets used in this paper do however supply TFP levels directly and therefore calculations for obtaining TFP values will not be necessary.

3.4. Technology Diffusion Model

The previous models discussed analyse how technological development affects economic growth in a region. The model concerning technology diffusion takes this a step further and studies how technology diffuses across borders and attempts to answer the question why different levels of technology are used in different countries. Jones and Vollrath (2013, p. 140) present an adapted Romer model in order to discuss the raised issues. In this model it is the level of human capital that serves as the main driver of economic growth and not the production of technology (*ibid*):

$$Y = K^{\alpha}(hL)^{1-\alpha}$$

As can be seen, the modification of the Romer model is that human capital replaces the level of technology. Therefore it is also the level of human capital that generates the increasing returns to scale. The reasoning is that a higher-skilled labour force is able to adopt and use a more advanced level of technology. This then enables the country to move closer to the technological frontier. Evidently, the technology diffusion model lends itself better to countries that do not produce their own technology. On the other hand the Romer model suits economies at the technological frontier.

With regards to the accumulation of capital and labour they are the same as in the previous Romer model. The accumulation of human capital, or skill, is however computed in the following way (Jones & Vollrath, 2013, p. 142):

$$\dot{h} = \mu e^{\psi u} A^{\gamma} h^{1-\gamma}$$

In this equation, A stands for the technological frontier and not the level of available technology in the country as earlier. Years of schooling and quality of education are denoted as ψ and u respectively. A parameter for the overall productivity in the acquisition of human capital is also included and is denoted as μ. It is usually assumed that $\mu>0$ (*ibid*). Finally, Υ is a parameter that reflects how important the technological frontier is to the development of the country's human capital. The larger the parameter is, the more important the world technology is for the development of human capital. It is known to lie between 0 and 1.

The main implication of this model is that the closer a country is to the technological frontier, the harder it is for the country to adopt newer technology. This can be clearly shown by rewriting the previous equation (*ibid*):

$$\frac{\dot{h}}{h} = \mu e^{\psi u} \left(\frac{A}{h}\right)^{\gamma}$$

The ratio of the technological frontier and human capital of the country can be said to correspond to the technology gap between the frontier and the country itself. If A is very large compared to h, the growth rate will be higher as it is easier to accumulate human capital. If the ratio is very small however, the growth rate will be smaller. This is supported by the notion that the more advanced a technology is, the harder it is to learn.

3.5. Schengen and Technology Diffusion

The technology diffusion model presented above recognizes the level of human capital to be a main driver for technology diffusion. It is therefore mainly in its ability to raise the level of human capital in the region that the Schengen Area can promote technology diffusion in a major way.

The European Commission (2014) has recently identified several perks for the labour market regarding the relevance of Schengen. Allowing workers to move freely to another member state may in many cases bring new job opportunities. In other words, Schengen may promote a better and more efficient matchmaking environment for employers and employees. Due to this, it may reduce unemployment disparities between member states and promote a more efficient allocation of human resources. It also opens up the possibility for workers to adopt new experiences and skills, such as learning a new language. These possibilities in turn work to increase the human capital within the region.

There are however possibilities for negative impacts due to simplified labour mobility. The European Commission (2014) acknowledges that certain countries may suffer from a brain drain of their most skilled workers. This would most likely result in skill shortages in certain sectors characterized by requiring advanced human capital. Microeconomic theory would however then suggest that high-skilled workers could receive higher wages due to a shortage in the suffering country. Why this is not the case in practice though may relate to differences in infrastructure between countries. Jones and Vollrath (2013) suggest that infrastructure may be an important source for growth. Without thoroughly exploring the theory behind it the authors do suggest that differences in infrastructure may be the reason for the differences in income between countries. As a result, all forms of labourers receive higher returns on their human capital due to more advanced infrastructure located in more developed countries. This outcome instead infers that the Schengen Area has a negative influence on the diffusion of technology.

4. Previous Research

Studies concerning either the TFP growth rate or the effect that the Schengen Area has had on various factors have been researched prior to this paper. The literature review in this section will first focus on recent research involving the factors that mainly influence the TFP growth rate in a specific country. Next, studies concerning the impact Schengen has had on mainly labour mobility and trade will be assessed.

This paper hopes to fill the void between research conducted with Schengen in mind and research that has not considered the area. This paper does so by combining the empirical strategy of studies that have previously analysed TFP growth with the Schengen Area.

4.1. Total Factor Productivity Growth

Previous empirical research has consistently regressed the TFP growth rate on the TFP gap and the TFP growth rate at the frontier. In most studies this is referred to as the basic specification. The TFP gap is a measure of the technology gap between the country in question and the country at the frontier. This variable is used to identify the extent of which the TFP growth in a country can be linked to the diffusion of newer technologies. The larger the gap, the larger are the gains from adopting newer technology (Havik et al., 2008). The

TFP growth rate at the frontier is simply the TFP growth rate of the country possessing the highest level of TFP, in other words technology. This variable is meant to capture the possible spillover effect of technology between the country at the frontier and the catching-up economies (European Commission, 2014).

Two previous studies that in large part have inspired the empirical strategy of this paper concern the TFP gap between the EU and the US as well as an evaluation of the TFP growth in the Euro area. Havik et al. (2008) explore the technological gap that has risen between the EU and the US in recent years. With the use of the EU KLEMS database the authors attempt to explore the factors that have influenced the rising gap. Using the same database, the European Commission (2014) instead study the technological development in the euro area.

Havik et al. (2008) find that both the TFP gap and TFP growth rate at the frontier are significant for a specific country's TFP growth rate. The TFP gap between the leader country and the country in question stands to be positively correlated with the TFP growth rate. Likewise, they find that the TFP growth rate at the frontier is positively correlated with the TFP growth rate of the specific country. The European Commission (2014) identifies the same relationship between the variables as Havik et al. (2008).

Besides slight variations of countries, years, and industries used the two studies also differ in approach. The European Commission (2014) investigates whether the variables alter in coefficient value and significance depending on time period. They do so by including all available[9] industries. Alternatively, Havik et al. (2008) interest themselves in differences across sectors of the economy. They do this specifically by identifying and pooling together either manufacturing, market services, or ICT-related industries. A large focus of their study is in fact devoted to the exploration of differences between sectors dependent on ICT and those that are not. A main hypothesis of their research is that ICT-related industries are more responsive to technology diffusion. However, no matter which combination of time periods and industries either study uses, the significance and coefficient sign of the two variables remain the same.

Beyond the basic specification, both studies also consider the impacts that high-skilled human capital, R&D, and ICT capital inputs have on the TFP growth of a country. The use of all three variables is supported by the existing theory surrounding them. The amount of high-skilled labour is expected to positively impact the possibilities of technology diffusion (Sondermann, 2012). Similarly, the amount spent on R&D is theorized to have a positive

[9] In terms of data availability.

impact. Lastly, ICT capital inputs are regarded as raising the quality of the existing capital stock (Marrocu, et al., 2013). The empirical results for these variables are however less consistent in both coefficients sign in addition to significance. The reports therefore draw only minor, if any, conclusions on the effect of them.

Apart from the basic specification Havik et al. (2008) also explore the role of regulations on the TFP growth rate of a country. Following their basic regression, an analysis including labour, product, and financial market regulation is performed. The Schengen dummy used in this paper will in some sense serve as a substitute for the labour and product market regulation variable. By investigating the Schengen Area however this paper attempts to shed light on how a specific regulation has affected the dependent variable in question rather than the general regulatory environment of the countries tested. The authors do however not find substantial evidence relating regulation to TFP growth rate performance in a country on the aggregate level. Instead they entertain the possibility of regulations as a variable to be highly sector specific.

4.2. Schengen

Studies concerned with the effect of the Schengen Area on economic variables are few. Two recent studies however investigate how the area has affected labour mobility and trade.

4.2.1. Labour Mobility

Biswas and McHardy (2004) identify that the flow of labourers across members of Schengen has increased to a greater extent than the flow between non-Schengen ones. Their study focuses on Southern European countries[10] and concludes that neighbouring countries experience the greatest effect of the increased labour mobility.

The authors report that the immigration and emigration patterns between the selected countries vary over time. Notably, they identify that Spain in particularly has had a significant influx of immigrants after the Schengen Agreement had been signed. Before the introduction of Schengen, Greece experienced a net inflow of migrants from Spain. This pattern reversed however the years following the Agreement. Similarly, Italy experienced a net inflow of migrants from the other countries before the Area was formalized. With the introduction of the Schengen Area however, Italy saw a net outflow of migrants to Spain and a large reduction in the net flow of migrants from Portugal. Though the authors present these findings

[10] Portugal, Spain, Italy, and Greece. France was omitted due to insufficient data.

Biswas and McHardy (2004) do not delve into any thorough explanation for the results obtained.

Expanding their study, they also find that the flow of labour within the region is partly dictated by historical ties and language similarity. This, they identified, is true even beyond the countries the study focused on in particular.

4.2.2. Trade

A recent study has also indicated that countries within the Schengen Area become closer trading partners (Davis & Gift, 2014). The authors suggest that this is mainly due to the increase in labour mobility which can in turn increase demand for foreign goods and spread information about foreign trading partners who might offer cheaper alternatives. Lastly, the report empirically demonstrates that both imports and exports increase as a consequence of Schengen membership.

Davis and Gift (2014) argue that the Schengen Area has affected trade in three central ways. First, the authors argue that immigrants introduce a preference for certain goods native to their home country and thereby increase the demand for such goods in the host country. In a first step, immigrants will import these goods possessing characteristics from their country of origin. A next step consists of new businesses entering the market to cater to the new demand for foreign goods. The authors identify that the demand for such goods will rise regardless of whether they become mainstream or not. Second, immigrants may be able to trade at a lower cost due to knowledge of low-cost foreign producers. Entrepreneurial immigrants can use their knowledge of their host and native country to deduce which suppliers offer the lowest prices. By being able to identify the comparative advantage of each country, trade flourishes. Third, Davis and Gift (2014) argue that the risks of trade are lowered as immigrants insert themselves into various social networks. The authors suggest that immigrant workers find themselves in a unique position with regards to negotiating cross-border contracts with suppliers from their native country. The knowledge that immigrants possess contributes to a less risky trade environment.

Using the gravity model the study is able to indicate that two countries being members of the Schengen Area increase their trade with each other by 0.1 per cent. Additionally, they find that a net increase in immigrants from one country to another of 1 per cent annually can increase trade between the nations by an equivalent amount. To put these figures into perspective the authors identify that the total amount of trade between for example Spain and Italy amounted to $50 billion in 2011. A 0.1 per cent increase of this figure would constitute for a $50 million increase of trade between the two countries every year. In other words, the percentages are of significant size.

5. Discussion of Data

The two main data sources used for this paper are the EU KLEMS together with the GGDC databases. The EU KLEMS database, funded by the European Union, is an effort to collect comparable data on a large range of variables throughout an extended period of time. O'Mahoney and Timmer (2009) provide a detailed review of the construction and application of the database. The GGDC is part of an effort of the University of Groningen to compile data in order to produce comparative analyses on economic performance. Together, the two databases offer a solid base to begin the analysis. It should be mentioned that the choice of years, countries, and industries included in this paper are completely influenced by the availability of data.

The advantage of the EU KLEMS and the GGDC databases is that they offer industry specific data, which increases the possibility for detailed results. Caution should however be taken regarding how specific and detailed the data in question is. A higher level of detail, in this case for industry data, usually corresponds with a higher degree of uncertainty for the estimated values (O'Mahoney & Timmer, 2009).

TFP levels for the year 1997, relative to the US, were supplied by the GGDC for the available countries and sectors. The data was extracted from the productivity level database, specifically the 1997 benchmark. Within this file the data is named MFP_VADD, standing for Multifactor productivity (value added based, double deflated). Inklaar and Timmer (2008) provide a discussion on single and double deflated values. The difference between the two values is that double deflation takes into account the price of intermediate inputs. If collected correctly, double-deflated data usually provide more precise values of the true figures and is in theory the preferred method to use. However, the double deflation method places larger requirements on the data and can because of this be more uncertain. The choice of using double deflated values in this paper is based on the availability of data rather than a preference for either method.

The EU KLEMS database provided the growth rates for TFP. The datasets for each country can be found in the March 2011 update of the ISIC Rev. 3. Data on TFP (value added based) growth can be found within each separate country file. The choice between value added and for example gross output measures is again due to the availability of data. Value added measures exclude intermediate inputs while gross output includes them (Cobbold, 2003). The advantage of excluding intermediate inputs is that the difficulty with inter- and intra-industry trade can be ignored. At the aggregate level the two measures supply similar values. At the industry level however the two measures can vary significantly. Though in theory the gross output measure may suite industry level data better, Cobbold (2003) identifies that most studies concerning TFP have used the value added measure.

The importance of ICT is in this paper measured as the share of total capital compensation that is directed towards ICT. This data can be found in the country files of the EU KLEMS March 2011 update of the ISIC Rev. 3 dataset.

Data on the R&D expenditure and gross output of each sector were collected from the OECD STAN database. R&D expenditure can be found in the ISIC Rev. 4 file while the gross output for the required countries can be found in the ISIC Rev. 3 file. Current prices for both variables were selected. Compared to the previous sources, the OECD STAN database is not able to supply a large amount of data. Necessary data is only available for a select few of countries and industries after the year 1998.

The level of human capital is in this paper represented by the share of labour compensation that reaches high-skilled labour. These figures are supplied by the EU KLEMS database, specifically in the labour input files in ISIC Rev. 4. High-skilled labour is defined as individuals who have completed tertiary education. Data for Japan is however extracted from the basic file in ISIC Rev. 3, also from the EU KLEMS database. As with the OECD STAN database, EU KLEMS is not able to supply large quantities of the desired variable. Apart from Japan, values are only available after the year 2001 for certain industries and countries. It should be noted that this causes Japan to be overrepresented when considering the role of human capital.

6. Method

A total of 12 OECD countries were included in the regression[11]. All countries except for Australia, Japan, the United Kingdom, and the US have become members of the Schengen Agreement over the course of the time period studied. Additionally, data was collected over

[11] Australia, Austria, Belgium, Denmark, Spain, Finland, France, Italy, Japan, Netherlands, the United Kingdom, and the US.

29 different industries rather than using the aggregate economy of each country[12]. As mentioned previously, the choice of countries and industries is based on the availability in the EU KLEMS and GGDC dataset.

6.1. Variables

6.1.1. Dependent Variable

The dependent variable of interest in this paper is the TFP growth rate of the countries included in the study. The data for this variable was collected from the EU KLEMS database as reviewed above. As covered in the theory section of this paper, TFP substitutes for the level of technology in a country. Consequently, the TFP growth rate used in this study acts as an indicator of the technological growth rate of the countries in question. The desire for technological growth with regards to economic development has been reviewed in earlier sections of this paper and will not be covered here.

6.1.2. Independent Variable

The aim of this paper is to shed light on whether the Schengen Area has contributed to the TFP growth within its borders and among its member states. Naturally, the independent variable is therefore whether a country is a member of the area or not. Countries that fulfil this requirement are given the value 1 while countries that do not are given the value 0. Important to note is that all countries start out with the value 0 as the time period studied begins before the Agreement was instated. Countries receive the value 1 once they have joined the area. This paper hypothesizes that joining the Schengen Area will have a positive effect on the technological level of a country due to a beneficial effect on the rate of technology diffusion.

[12] AtB (Agriculture, hunting, forestry, and fishing), C (Mining and quarrying), D (Total Manufacturing), 15t16 (Food, beverages, and tobacco), 17t19 (Textiles, textile, leather, and footwear), 20 (Wood and of wood and cork), 21t22 (Pulp, paper, printing, and publishing), 23 (Coke, refined petroleum, and nuclear fuel), 24 (Chemicals and chemical products), 25 (Rubber and plastics), 26 (Other non-metallic minerals), 27t28 (Basic metals and fabricated metal), 29 (Machinery), 30t33 (Electrical and optical equipment), 34t35 (Transport equipment), 36t37 (Manufacturing, NEC), E (Electricity, gas, and water supply), F (Construction), G (Wholesale and retail trade), H (Hotels and restaurants), 60t63 (Transport and storage), 64 (Post and telecommunications), J (Financial intermediation), 70 (Real estate activities), 71t74 (Renting of m & eq and other business activities), L (Public admin and defence), M (Education), N (Health and social work), and O (Other community, social, and personal services).

6.1.3. Control Variables

The technological gap between the studied countries represents the difference in technological level between the countries in question. The technological gap hopes to capture the extent of which countries not at the technological frontier adopt frontier technologies. As reviewed in the theory of this paper, the larger the gap the easier it should be for the country to adopt new technology. Contrastingly, it is anticipated that a small gap should make it harder for the country to close the gap.

The GGDC dataset provided TFP levels relative that of the US for the countries in question for the year 1997. Additionally, the EU KLEMS dataset provided TFP level growth values using 1995 as a base year. The TFP gaps for all countries and industries throughout the necessary time period were computed by using both datasets. First, the 1997 TFP levels were expanded to cover all the years between 1983-2006 by applying the TFP growth rates supplied by the EU KLEMS dataset. Using the now available TFP levels and growth rates for each country and industry the TFP gap for each country, year, and industry was calculated[13]. Due to its nature, the values of the TFP gap are negative with the exception of when the country is at the frontier itself. For these cases the value of the TFP gap is 0. It is hypothesized that the TFP gap affects the TFP growth of a country positively, as is expected from theory and has been the case in previous studies. In other words, the coefficient should be negative.

The TFP growth rate at the frontier is simply the TFP growth rate of the country with the highest TFP level in the selected year and industry. This variable is meant to capture the extent of innovation spillovers that occur between the country at the frontier and the catching-up countries. It is expected that the growth rate at the frontier and the growth rate of the catching-up economies are positively correlated.

A third control variable is used in the form of total capital compensation that reaches ICT. As previous research has implied, the amount of ICT present in the production of goods and services correlates with the quality of the capital inputs. Due to its relation with the quality of capital it is expected that a greater amount of ICT compensation within an industry correlates with a higher TFP growth rate. It should however be noted that the correlation between ICT compensation and the TFP growth rate has fluctuated both within and between studies. Both positive and negative correlations have been documented.

[13] Lagged $\ln(\text{TFP level}_{i,j,t-1}) - \ln(\text{TFP level at the frontier}_{i,j,t-1})$

The two final variables included in the empirical study are R&D expenditure and high-skilled human capital. The amount of R&D expenditure of each industry is computed as a percentage using data on total R&D expenditure and total gross output in each industry, country, and year. This variable is meant to control for the role of R&D and its effect on the TFP growth rate. In this paper, the share of labour compensation that reaches high-skilled labour determines the role of human capital. Theory expects both these variables to be positively correlated with the TFP growth rate. However, empirically the role of human capital has varied.

6.2. Regressions

Two regressions are included in this paper and are produced using the STATA software. The analysis includes panel data over an extended time period, including various countries and industries. Both regressions include time, country, and industry fixed effects, which are shown by the corresponding dummy variables. The subscripts i, j, and t stand for country, industry, and year respectively. The basic regression covers the two variables previously discussed, TFP gap and the TFP growth rate at the frontier, plus a dummy variable for Schengen participation.

$$TFP\ Growth_{i,j,t} = \beta_0 + \beta_1 TFP\ GAP_{i,j,t-1} + \beta_2 TFP\ Frontier_{i,j,t} + \beta_3 D_{Schengen} + \beta_4 D_i + \beta_5 D_j + \beta_6 D_t + \varepsilon_{i,j,t} \quad (1)$$

The basic regression is then expanded to include the remaining three control variables.

$$TFP\ Growth_{i,j,t} = \beta_0 + \beta_1 TFP\ GAP_{i,j,t-1} + \beta_2 TFP\ Frontier_{i,j,t} + \beta_3 ICT + \beta_4 R\&D + \beta_5 Human\ Capital + \beta_6 D_{Schengen} + \beta_4 D_i + \beta_5 D_j + \beta_6 D_t + \varepsilon_{i,j,t} \quad (2)$$

7. Empirical Analysis

The basic (1) and advanced (2) regressions are presented below. The first column in both regressions includes all years with available data. Different time periods are considered in the following columns and are regarded as robustness tests.

7.1. Diagnostic Tests

A number of tests and robustness checks are executed and are displayed in the appendix of this paper. A Hausman test is performed to determine whether the model requires fixed or random effects. Fixed effects are required in order to study changes within an entity (Torres-Reyna, 2007). In this case the null hypothesis is rejected for both the basic and advanced regression and so fixed effects are applied to countries and industries. Additionally, a time-fixed effects test is performed to determine whether time dummies are needed. As previously, this is to assess changes through time. Accordingly, time-fixed effects are deemed necessary.

Since the data covers an extended time period it is recommendable to perform a serial correlation test. In practice, serial correlation results in small standard errors in addition to an overestimated R-squared. A Wooldridge test reveals that the basic regression suffers from serial correlation while the advanced regression does not. Finally, a Wald test reveals that the data used suffers from heteroskedastic standard errors. This entails that the variance of the error terms are not constant (Williams, 2015). Where necessary, robust standard errors have been applied correcting for serial correlation and heteroskedasticity.

7.2. Basic Regression

As seen below, the TFP growth rate is regressed on the TFP gap, the TFP growth rate at the frontier as well as a Schengen dummy.

Table 1: Basic Regression

VARIABLES	(1) All Years TFP Growth Rate	(2) 1990-2006 TFP Growth Rate	(3) 2000-2006 TFP Growth Rate
TFP Gap	-0.07301***	-0.13597***	-0.37354***
	(0.01155)	(0.02894)	(0.12303)
TFP Frontier	0.09920*	0.12075*	0.23160***
	(0.05273)	(0.06258)	(0.05439)
Schengen	0.00381	0.00366	0.01725
	(0.00314)	(0.00361)	(0.01278)
Constant	-0.03325***	-0.09239***	-0.28105***
	(0.00864)	(0.02395)	(0.09732)
Observations	8,352	5,916	2,436
R-squared	0.05062	0.11496	0.17466

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As can be seen above, the TFP gap between the frontier and catching-up economies produced a significant and positive correlation. Since the TFP gap only contained values less than zero, except for the country at the frontier, the negative value of the coefficient implies that the technology gap enables higher potential gains for the catching-up economies. The TFP gap remains strongly significant along all time periods as well.

The TFP growth rate at the frontier seems to have a positive and significant effect on the TFP growth rate of the country in question throughout all time periods. This supports the notion that a higher TFP growth rate at the frontier can positively affect the TFP growth rate in catching-up economies.

Membership in the Schengen Area is not found to be significant in any of the time periods tested.

7.3. Advanced Regression

The regression below includes three additional variables in the form of ICT compensation, R&D expenditure, and high-skilled human capital. The R&D expenditure and high-skilled human capital variables are only included in the last time period due to data constraints.

Table 2: Advanced Regression

VARIABLES	(1) All Years TFP Growth Rate	(2) 1990-2006 TFP Growth Rate	(3) 2000-2006 TFP Growth Rate
TFP Gap	-0.07660***	-0.14105***	-0.36683***
	(0.01366)	(0.03008)	(0.08665)
TFP Frontier	0.10246**	0.12371**	0.33893***
	(0.05109)	(0.06124)	(0.09270)
ICT Compensation	-0.10396**	-0.12715***	-0.09698**
	(0.04797)	(0.04359)	(0.03973)
R&D Expenditure			-1.42426*
			(0.84752)
High-skilled Human Capital			0.21480
			(0.34810)
Schengen	0.00102	0.00107	0.07091**
	(0.00331)	(0.00364)	(0.03450)
Constant	-0.02610***	-0.07569***	-0.38089***
	(0.00811)	(0.02108)	(0.09921)
Observations	8,304	5,882	386
R-squared	0.05806	0.12570	0.21638

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As with the basic regression, the TFP gap is found to be strongly significant and positively correlated with the TFP growth rate of a country. The TFP growth rate at the frontier is also found to be significant and positively correlated with the growth rate of catching-up economies. These results correspond to theory as wells as previous empirical studies.

Both ICT compensation as well as R&D expenditure are found to be significant and negatively correlated with the TFP growth rate. High-skilled human capital is not found to significantly correlate with the independent variable.

Schengen membership is found to be positive and significant in the last time period as can be seen in the third column above.

8. Discussion of Results

As TFP values are only estimates of the level of technology a discussion concerning exact coefficients is ignored. Rather, weight will be placed on coefficient signs together with significance of the variable.

The basic regression performed above largely reflects the previous empirical work done on the subject. Both coefficient signs and significance levels coincide with the previous research reviewed in this paper. These results also confirm the existing theory on the subject. The advanced regression confirms this view as well. The results demonstrate that a larger TFP gap between the catching-up countries and the country at the frontier results in a higher TFP growth rate of the former.

Similarly, the results of the TFP growth rate at the frontier coincide both with previous empirical research and theory in the basic and the advanced regression. The TFP growth at the frontier is found to be positively correlated with the TFP growth rate of a catching-up economy. This supports the view that a certain degree of innovation spillover occurs between the frontier and the following countries. These results can however also be scrutinized as above.

The advanced regression proceeds to include additional control variables that are regarded to affect the TFP growth rate. The role of ICT compensation is found to be significant and negative across all time periods. This implies that a higher quality of capital input correlates with a lower TFP growth rate. As reviewed previously, this result has been obtained in earlier studies as well. A possible explanation relates to the theory of the TFP gap. Better quality inputs indirectly correspond to a greater difficulty to adopt newer capital inputs. This effect can unfold in two ways. Firstly, it takes more time to learn, or adopt, more advanced capital as, naturally, it is more complicated. Secondly, the newer a country's capital stock is, the more resistant it will be to adopt new technology again. As can be noted, the sample includes mainly advanced economies, which can imply that the capital stock was quite advanced from the start and therefore the countries have not been adopting better quality capital regularly.

In this paper, the importance of R&D expenditure is found to be negative while the role of high-skilled human capital is not found to be significant. This unfortunately does not confirm previous theory on economic growth. However, the results obtained above do to some degree reflect results published in previous studies. The roles of these two variables have rarely been found to be significant and coefficient signs do vary, contradicting theory on the subject. Important to note is however that the sample size had to be drastically reduced in order to include the R&D expenditure and high-skilled human capital variables as can be seen in the table above. This reduces the reliability of the results as they only reflect a small amount of countries over a limited time period. It is also worth reflecting on whether the effects of these variables are only seen over time or perhaps unfold with long lags. It is reasonable to speculate that resources devoted to R&D only affect the gross output of an industry after a longer period of time. In other words, R&D expenditure needs time to develop. Instead, the results above could imply that R&D expenditure burdens the TFP growth rate in the short-run. It is possible that these reasons also apply to the role of high-skilled labour.

Membership in Schengen is not found to be significant in the basic or the advanced regression except for in the last time period tested. For the period 2000-2006 the effect of the Schengen Area is significant and positive. This in turn means that becoming, or staying, a member of Schengen may impact the TFP growth rate positively. The theory reviewed in this paper presents certain support to why the Schengen Area should affect the TFP growth rate of a country. The results above demonstrate that there may be certain empirical support for this notion. A possible explanation to why the effect is only significant in the last time period may be that Schengen participation affects the TFP growth rate gradually and over a relatively long period of time. In other words, the effects may only be recorded in the most recent years. When instead including an extended time period the effects may be diluted and therefore not show significance in the first columns.

The significant results above imply that Schengen membership is positively correlated with the TFP growth rate. This result has however been obtained using a relatively homogenous group of countries. All the countries in this study are acknowledged as advanced economies and are all part of OECD. Furthermore, all countries included are located in Western Europe apart from the US, Japan, and Australia. This could imply that the countries are all relatively close to the frontier. It can be speculated that less developed countries within Schengen may suffer from brain drain, resulting in a lower level of human capital. In that case, Schengen membership would affect the diffusion of technologies negatively.

Additionally, it is worth noting that many of the Schengen countries in this study are also members of the European Monetary Union (EMU). In fact, of the included countries Denmark is the only Schengen member that does not use the Euro. Though each country entered the monetary union and the Schengen Area at different times it is plausible that the significant effect identified above is inflated by the Euro. In other words, the results produced in this study may reflect a combined effect of the Area and monetary union acting together.

9. Conclusion

The aim of this paper is to examine whether the Schengen Area has had any effects on the technology diffusion among its members. The motivation to answer this question lies in the interest of policy makers to deepen their understanding of the ambitious project. In turn, this paper hopes to illuminate new research questions concerning Schengen that have not previously been studied.

This paper utilizes previous research done in the area of technology diffusion and applies it on the Schengen Area. By exploiting recognized regression models this paper is able to in part replicate as well as expand the application of endogenous growth theory, specifically related to technology diffusion. As technology in itself is close to immeasurable, the TFP level of each country is instead used to indicate the technological level. Data is predominantly collected from the EU KLEMS and GGDC databases which allow for detailed industry level data rather than aggregate.

The TFP growth rate is initially regressed on the TFP gap between the frontier country and the catching-up countries, the TFP growth rate at the frontier, plus a Schengen dummy. The TFP gap variable is meant to capture the diffusion of new technologies while the TFP growth rate at the frontier attempts to incorporate the spillover effects of newer technology. The basic regression is then expanded to include further control variables in the form of ICT compensation, R&D expenditure, and share of high-skilled human capital.

The significance and coefficient signs of the control variables included match to a large degree previous research that has been conducted in the area. This is the case specifically for the TFP gap and the TFP growth rate at the frontier as consensus regarding their effects has been reached prior to this study. Surprisingly, both ICT compensation and R&D expenditure seemed to be negatively correlated with the TFP growth rate. The effect of high-skilled human capital turned out to be inconclusive in this study, which has been the case in previous research.

Whether the Schengen Area itself has impacted the technology diffusion within the region and if so to what degree remains to be determined. This paper offers a first attempt to analyse the effect of Schengen on technology diffusion and the results vary. Due to the inconclusive results it is unreasonable at this time to disregard the Schengen Area from having an impact on technology diffusion. However, it should be stressed that the opposite is also true. Further research on the area is much welcomed.

Data constraints are certainly a substantial factor impacting the countries, industries, as well as years studied. However, with time, future research could revisit the question at hand using a more modern time period. Including later years may allow the impact of Schengen to present itself more clearly considering that the effects may be gradual and occur over time. Additionally, including a more diverse set of countries can also shed more light on whether the Schengen Area impacts its member countries positively or negatively. In this case, using advanced economies, the significant result was positive. A study including less advanced member states that may suffer from brain drain could however render a different outcome. Moreover, an ideal study would perhaps test the role of Schengen at border crossings rather than the whole Schengen region. It is reasonable to assume that the effect of no border controls impact the citizens who make use of it the most, in other words, cross-border commuters. Data to be collected and comparable on small regions like this is however very unlikely.

Lastly, it is worth noting that the results propose that Schengen may offer more benefits to the economy than previously thought. The Agreement signed in 1985 may, apart from affecting the movement of goods and people, also affect the technological growth of the region. It is therefore recommendable to consider this when the future of the Area is assessed.

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Appendix

A.1. Basic Regression

A.1.1. Hausman Test

In order to determine whether fixed or random effects were most appropriate for this model a Hausman test was executed. The null hypothesis states that a random effects model is preferred. The results, shown in the table below, identify that a fixed effects regression is preferred.

Table A.1

	Coefficients (b) fixed	(B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
lnTFPGAP	-.0740659	-.0218956	-.0521702	.00374
TFPFrontier1	.1019418	.1105694	-.0086277	.0025031
Schengen	-.0041793	-.0039821	-.0001972	.0007228

```
                    b = consistent under Ho and Ha; obtained from xtreg
     B = inconsistent under Ha, efficient under Ho; obtained from xtreg

 Test:  Ho:  difference in coefficients not systematic

               chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                       =      315.08
             Prob>chi2 =      0.0000
```

A.1.2. Time Fixed Effect Test

Once a fixed effect model is established it is necessary to test whether the regression also requires time fixed effects. The null hypothesis states that the coefficients for all years are jointly equal to zero. As can be seen in the table below we reject the null hypothesis.

Table A.2

```
( 1)  _IYear_1984 = 0
( 2)  _IYear_1985 = 0
( 3)  _IYear_1986 = 0
( 4)  _IYear_1987 = 0
( 5)  _IYear_1988 = 0
( 6)  _IYear_1989 = 0
( 7)  _IYear_1990 = 0
( 8)  _IYear_1991 = 0
( 9)  _IYear_1992 = 0
(10)  _IYear_1993 = 0
(11)  _IYear_1994 = 0
(12)  _IYear_1995 = 0
(13)  _IYear_1996 = 0
(14)  _IYear_1997 = 0
(15)  _IYear_1998 = 0
(16)  _IYear_1999 = 0
(17)  _IYear_2000 = 0
(18)  _IYear_2001 = 0
(19)  _IYear_2002 = 0
(20)  _IYear_2003 = 0
(21)  _IYear_2004 = 0
(22)  _IYear_2005 = 0
(23)  _IYear_2006 = 0

      F( 23,  7978) =    2.36
           Prob > F =    0.0003
```

A.1.3. Serial Correlation Test

Testing for serial correlation is advisable when using macro data that stretches beyond 20 years. Serial correlation can cause smaller standard errors and a larger R-squared. A Wooldridge test for autocorrelation was performed as can be seen below. The null hypothesis states that no autocorrelation exists. The results indicate that we reject the null hypothesis.

Table A.3

```
Wooldridge test for autocorrelation in panel data
H0: no first order autocorrelation
    F(  1,     347) =     11.805
           Prob > F =      0.0007
```

A.1.4. Heteroskedasticity Test

A Wald test was performed in order to test for heteroskedasticity. The null hypothesis in this case is homoskedasticity. As can be seen in the table below we reject the null hypothesis and find evidence of heteroskedasticity.

Table A.4

```
Modified Wald test for groupwise heteroskedasticity
in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (348)  =    3.5e+05
Prob>chi2 =       0.0000
```

A.2. Advanced Regression

A.2.1. Hausman Test

As with the basic regression a Hausman test was executed. The null hypothesis states that a random effects model is preferred. The results, shown in the table below, identify that a fixed effects regression is preferred.

Table A.5

	Coefficients (b) fixed	(B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
lnTFPGAP	-.1293421	.0051097	-.1344518	.0221441
TFPFrontier1	.0659018	.0321907	.033711	.0064598
ICTCapital	-.069443	.015591	-.085034	.0444829
RD	-.5434979	.6440463	-1.187544	.5656196
HumanCapital	-.5340263	-.0536355	-.4803908	.1318414
Schengen	.0168104	.0018136	.0149968	.0105477

```
                 b = consistent under Ho and Ha; obtained from xtreg
  B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test:  Ho:  difference in coefficients not systematic

              chi2(6) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                      =       33.50
            Prob>chi2 =      0.0000
```

A.2.2. Time Fixed Effect Test

A time fixed effects test was also executed for the advanced regression. The null hypothesis was rejected as can be seen below.

Table A.6

```
( 1)  _IYear_1987 = 0
( 2)  _IYear_1988 = 0
( 3)  _IYear_1989 = 0
( 4)  _IYear_1990 = 0
( 5)  _IYear_1991 = 0
( 6)  _IYear_1992 = 0
( 7)  _IYear_1993 = 0
( 8)  _IYear_1994 = 0
( 9)  _IYear_1995 = 0
(10)  _IYear_1996 = 0
(11)  _IYear_1997 = 0
(12)  _IYear_1998 = 0
(13)  _IYear_1999 = 0
(14)  _IYear_2000 = 0
(15)  _IYear_2001 = 0
(16)  _IYear_2002 = 0
(17)  _IYear_2003 = 0
(18)  _IYear_2004 = 0
(19)  _IYear_2005 = 0

      F( 19,   509) =    3.17
           Prob > F =    0.0000
```

A.2.3. Serial Correlation Test

The outcome of the Wooldridge test differs for the advanced regression. In this case we fail to reject the null hypothesis.

Table A.7

```
Wooldridge test for autocorrelation in panel data
H0: no first order autocorrelation
    F(  1,      61) =      3.615
           Prob > F =      0.0620
```

A.2.4. Heteroskedasticity Test

The advanced regression also has evidence of heteroskedasticity as we reject the null hypothesis.

Table A.8

```
Modified Wald test for groupwise heteroskedasticity
in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (68)  =    4.4e+32
Prob>chi2 =      0.0000
```