JÖNKÖPING UNIVERSITY
International Business School

Economic Performance and R&D

BACHELOR
THESIS WITHIN: *Economics*
NUMBER OF CREDITS: *15 ECTS*
PROGRAMME OF STUDY: *International Economics*
AUTHOR: *Fia Andersson and Tilda Fredriksson*
JÖNKÖPING *June 2018*

Acknowledgements

We, the authors, would like to take the possibility to acknowledge the individuals showing support during the process of writing this thesis.

Firstly, we would like to send our gratitude to our mentors, which have provided irreplaceable and supportive advices throughout the process.

Secondly, to our common seminar participants for supplying advantageous and sound ideas during the meetings.

Lastly, we would like to recognise our families and friends for being there and being encouraging during the entire project

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June, 2018

Bachelor Thesis in Economics

Title: Economic Performance and R&D
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Date: 2018-06-06

Key terms: Research and Development, Economic Growth, Endogenous Growth Theory, Granger Causality, Toda-Yamamoto, Income Groups

Abstract

Researchers tend to disagree on the direction of the relation among R&D and economic growth, suggesting that if economic performance determines R&D investments countries might overinvest in their R&D expenditure. The purpose of this thesis is therefore to shed new light to this question by first establishing a relation among the variables and thereafter investigate the Granger causality between them. This paper is based on a panel study consisting of 60 countries, with various levels of income during the period 1996-2015. Using a fixed effects model, we can establish a positive relation between growth in R&D expenditure and GDP growth and using Granger causality tests and the Toda-Yamamoto augmented Granger causality tests, we can conclude that the growth of R&D expenditure determines economic performance in the short-run for countries in all income levels, however no conclusions can be made regarding the direction of Granger causality in the long-run. Hence, our results show that R&D investments stimulate economic growth and should, to some extent, be favoured by policy regardless of a nation's level of development.

Abbreviations

ADF	Augmented Dickey Fuller
CPI	Corruption Perception Index
FEM	Fixed Effects Model
GDP	Gross Domestic Product
GNI	Gross National Income
OLS	Ordinary Least Squares
R&D	Research and Development
REM	Random Effects Model
VAR	Vector Autoregressive

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1 Introduction

This chapter provides the reader with the motivation and purpose of the topic chosen, as well as an overview of method and main results.

Two of the most well-known researchers analysing economic growth, Romer (1990) and Solow (1957), both conclude that long-run growth is driven by nothing except technological change. This technical change derives from investments in research and development (R&D), in which R&D being the creation or improvement of new goods or alterations of production strategies to increase efficiency. Researchers such as Grossman and Helpman (1994), Lhuillery and Miotti (2008) and Sørensen (1997) establish a relation among R&D and economic performance. Although researchers can ascertain a relationship, it is less straightforward to interpret the empirical results due to the issue of endogeneity. The endogeneity problem regards the question whether R&D causes economic growth or economic growth causes R&D. Knowing that there is a relationship among R&D and GDP growth, one might expect the direction of causality among high-income economies and low-income economies to be different. This can further be connected to the so-called R&D paradox, meaning that countries with the largest R&D expenditure are not always the ones growing the most rapidly, indicating that after a certain threshold it demands more for an economy to grow (Brown & Svensson, 1988; Hall & Oriani, 2006; Minniti & Venturini, 2017). However, studies investigating the causality between R&D and GDP growth on income classifications in the world, have been somewhat overlooked in more recent years, meaning that countries might overinvest in their R&D expenditure if it can be concluded that GDP growth causes the amount of R&D investments.

It is therefore of interest to investigate the endogeneity problem further using short-term and long-term tests of Granger causality. Our study aims not only to confirm the relation of R&D and GDP growth but rather to shed new light on the issue of endogeneity, among countries with different income levels. However, this thesis differs from the studies mentioned above in multiple ways. This study is conducted on a world level, dividing the countries into income groups, thus not only including more countries but also focusing on a different division of countries, specifically income groups all over the world. Moreover, the study will be conducted on an extended period, specifically including more recent years, which is rarely occurring in previous studies. Hence the purpose is twofold, firstly we establish if R&D is related to economic growth, by investigating the following research question: Does the level of R&D expenditure have a positive relationship with economic growth over time? Secondly, we investigate whether R&D Granger causes gross domestic product (GDP) growth or vice versa between countries with diverse levels of income, since one would expect the Granger causality to be different among the different income groups, by asking: How does the Granger causality between R&D expenditure and GDP growth look like among countries with various income levels?

To answer these research questions, the econometric analysis is based on a sample of 60 countries with different income levels around the world between 1996-2015. The first research question is tested by different model specifications, including: capital, labour, R&D, trade and corruption, the appropriate model specification is thereafter applied to a fixed effects model (FEM) to establish a relation among GDP growth and R&D. Thereafter, the sample is divided into different sub-samples according to the income classification provided by the World Bank. These income classifications are as follows: high-income, upper-middle-income, and lower-middle-income. Low-income is excluded due to lacking data availability. The second research question is investigated by conducting a Granger causality test and Johansen's cointegration test in combination with the Toda-Yamamoto augmented Granger causality test on the different income levels, to determine the direction of Granger causality among R&D expenditure and GDP growth.

By carrying out a FEM one can conclude a positive relationship among R&D growth and economic performance during the 20 years investigated. However, conducting a Wald's test confirms that the R&D variable is endogenous, meaning that the FEM is not appropriate for estimating or testing and even less forecasting. This leads us to the second research question, which specifically addresses the issue of endogeneity. A Granger causality test is conducted, indicating how the growth of R&D influences GDP growth in the short-run for all income levels in the sample. However, the Toda-Yamamoto augmented Granger causality test indicates that the direction of Granger causality among the regarded variables is unestablished in the long-run regardless of income level. This suggests conflicting results for the long-run test, since the Johansen's cointegration test, performed in combination with the Toda-Yamamoto approach, indicates cointegration between the variables in the long-run, meaning that these two tests contradict each other.

The structure of the paper is therefore as follows: *Section 2* - Background, provides the reader with an overview of relevant statistics and figures regarding R&D spending in different countries and different income levels. *Section 3* – Previous Research, discusses endogenous growth theory, which is fundamental for the analysis. Moreover, previous empirical findings are summarised. *Section 4* - Empirical Framework, provides a thorough description of the methodology used and the empirical model. Moreover, diagnostics tests and robustness tests are touched upon. And lastly, Granger causality tests, testing both short run and long run are considered. *Section 5* - Empirical Results and Analysis, presents results and analyses these, connecting back to the previous research. *Section 6* - Conclusion, summaries the paper, stresses importance of certain aspects for society and science and concludes with limitations and suggested future research.

2 Background

This chapter presents basic facts and figures regarding R&D expenditure in different countries.

The world´s R&D expenditure as percentage of GDP does not depict a straight upward trend (seen in figure 2.1), rather it has varied from a minimum of 1.95 percent of GDP to a maximum of 2.23 percent of GDP between the years 1996-2015. First in 2007 the world experienced a sustained upward trend in R&D spending as a share of GDP, due to the level of R&D expenditure growing more rapidly than GDP (World Bank, 2018a). Although the overall spending of R&D as a percentage of GDP increases in the world, the geographical allocation portrays a highly unequal picture (see figure 2.2), not only among high-income economies and lower-income economies but one can further observe discrepancies among high-income economies themselves.

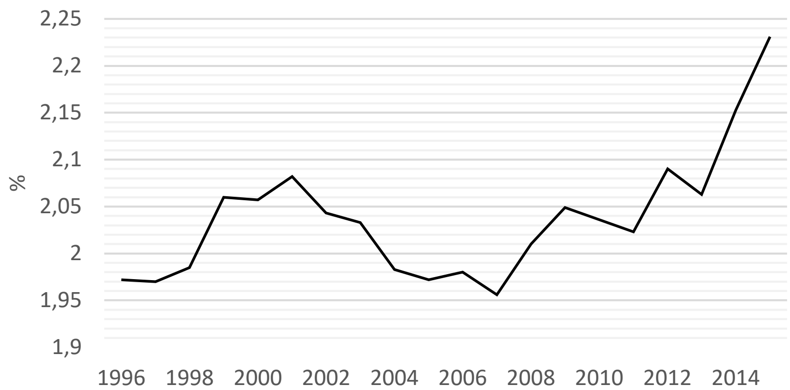

Figure 2.1 R&D expenditure (% of GDP) in the world (1996-2015).
(Source: The World Bank, 2018a)

Analysing the average R&D spending as a percentage of GDP of each of the individual countries in the sample, one can conclude that Europe, Asia and the United States are in the front edge of R&D expenditure relative to GDP (see appendix A). Additionally, from the sample one can confirm the differences in R&D spending as a percentage of GDP among the high-income economies, this becomes especially apparent considering Trinidad and Tobago which has an average R&D spending of 0.079 percent of GDP compared to United States which has an average R&D spending of 2.661 percent of GDP. In the upper-middle-income category, China, Brazil and Russia stand out due to their relatively high values, each with an average R&D spending as a percentage of GDP of 1.481, 1.072, 1.120. These are part of BRIC, which symbolises fast growing economies (UN News, 2017). In the lower-middle-income economies only two countries stand out, this is Ukraine and India, with average R&D expenditure as a percentage of GDP of 0.881 and 0.771, respectively. India is moreover a BRIC member. Other countries in the lower-middle-income group have an average R&D expenditure as a percentage of GDP ranging from 0.093 to 0.422. From table 2.1, providing an outlook of descriptive statistics for the three income groups in the sample, one can observe the highest mean spending on R&D in the high-income group, followed by upper-middle-income and lastly lower-middle-income.

Table 2.1 Descriptive statistics for income groups during 1996-2015

Descriptive Statistics R&D and GDP Growth 1996-2015								
	All Income Groups		High-Income		Upper-Middle-Income		Lower-Middle-Income	
	GDP Growth (%)	R&D	GDP Growth (%)	R&D	GDP Growth (%)	R&D	GDP Growth (%)	R&D
Mean	0.3622	16.800	0.3271	25.000	0.1962	7.8600	0.7172	3.9500
Median	0.0639	1.2000	0.0518	3.3900	0.0884	0.5470	0.0917	0.0629
Maximum	151.05	506.00	151.05	506.00	43.341	229.00	88.560	49.100
Mimimum	-0.9992	0.0009	-0.9992	0.0006	-0.9974	0.0009	-0.9637	0.0031
Std.dev	5.4755	53.100	6.0561	67.800	2.2891	24.600	7.6195	9.1600

R&D values are in billions U.S. dollar

(Source: The World Bank, 2018a)

Comparing figure 2.2 displaying the allocation of R&D expenditure relative to GDP in the world, with figure 2.3 portraying GDP growth in all countries, one can observe a contrasting picture. Countries with higher R&D expenditure relative to GDP do not show to be the ones growing the most rapidly. This picture is maybe not what one would expect, rather one would expect countries spending more on R&D to grow faster, meaning that R&D would Granger cause GDP growth whereas for lower-income economies one might expect GDP growth to Granger cause R&D (Goni & Maloney, 2014). Countries that spend the most on R&D do not grow as much as the ones spending less, depicting the R&D paradox.

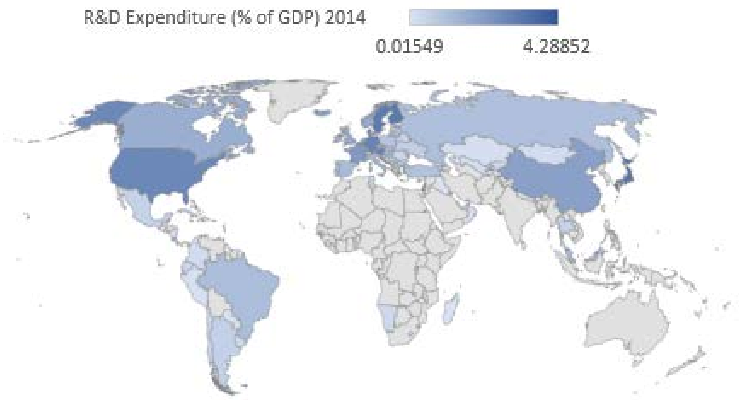

Figure 2.2 Allocation of R&D expenditure (% of GDP) in the world (2014).
(Source: The World Bank, 2018a)

Figure 2.3 Allocation of GDP growth in the world (2014).
(Source: The World Bank, 2018b)

The same pattern can be observed regarding the sample of the paper, looking at the descriptive statistics on R&D expenditure and GDP growth in table 2.1. Comparing income groups, one can conclude that the high-income group has the highest mean R&D expenditure in absolute terms, however, one can additionally observe that it does not have the highest mean GDP growth. The lowest mean GDP growth can be observed for the upper-middle-income group even though they spend more on R&D in absolute terms than the lower-middle-income group. The income group growing the most but also spending the least on R&D in absolute terms is the lower-middle-income group, thus somewhat confirming the R&D paradox. However, also bear in mind that less wealthy economies might portray higher GDP growth rates due to reasons other than simply the R&D paradox, for instance increasing capital accumulation, leading to above normal growth rates (Solow, 1956).

This relates to the catch-up effect and the marginal returns to economic growth. Emerging countries generally have a higher marginal return to GDP growth than developed economies, meaning that poorer countries experience a more rapid increase in economic growth since every input used in production is more productive than for higher-income economies. This also implies that developed economies will reap relatively less benefits from adding one extra unit of input (capital and labour) into production, meaning that they will observe a threshold level concerning economic growth (Solow, 1956). More recent studies agree upon a similar argument, that R&D becomes less of an important input in production the wealthier an economy is, meaning that one can observe a threshold level also within the R&D sector (Lederman & Maloney, 2003; Minniti & Venturini, 2017).

Another explanation to the R&D paradox put forward by UNESCO (2015) is how initiatives in R&D are mostly conducted by the private sector. This indicates a converging trend, where high-income economies spend less on R&D in the public sector, whereas the private sector has either grown or maintained. Moreover, high-income economies invest in R&D to stay competitive in the global market. The same cannot be concluded for lower-income economies, rather one can observe increasing investments in R&D on a public level, used as a growth strategy to improve economic performance. What UNESCO (2015) concludes for all income groups are that they strive to have the most talented researchers which leads to investments in higher education and research laboratories. Private firms, on the other hand, can easier reallocate research infrastructure to benefit from countries with labour-intensive populations, meaning that lower-income economies reap the largest benefits from production. When countries, on all income levels, invest in researchers and public R&D, this increase the initiative for the private sector to tap into R&D. Although, private and public initiatives in R&D have different targets, economic growth depends on how well they complement each other (UNESCO, 2015).

3 Previous Research

This chapter provides relevant theories regarding economic growth and presents the hypotheses tested in this study.

3.1 Growth Theory

Solow (1956) brings forward one of the first mathematically derived growth models, stressing the importance of capital and labour accumulation. Furthermore, Solow (1957) makes the substantial conclusion that long-run growth is driven by nothing except technological progress. However, the model does not conclude what drives the technological progress, thus technology is exogenous. Romer (2012) argues that the endogenous growth model was developed as a response to consider economic growth further. The main difference between the endogenous growth model and the Solow model is how technology is treated, in which the first defines four microeconomic factors that determines the level of R&D, compared to Solow's model in which it is exogenous.

Romer (1990) presents an endogenous growth model, with the idea of R&D being motivated by private profits from innovation, which in turn increase the incentives to further investment in R&D. The model assumes that knowledge consists of dissimilar ideas and are therefore imperfect substitutes. An additional assumption made is monopoly rights for the developer, excluding others from using the idea, hence also allowing for temporary monopoly profits. Moreover, capital is excluded since it complicates the model´s implications due to transition dynamics, meaning that the economy does not move directly to its new balanced growth route. Hence, the exclusion of capital simplifies the calculation and the analysis of the model´s main points. On the other hand, when including capital, analyses can be conducted on the distribution of output among investment and consumption due to policies, which is not possible in the previous scenario. However, since the model´s main purpose is the same, both including or excluding capital, the most efficient choice is to exclude it. With this simplification, the model's key equation is:

$$\frac{\dot{Y}(t)}{Y(t)} = \max\{\frac{(1-\emptyset)^2}{\emptyset}B\bar{L} - (1-\emptyset)\rho, 0\}$$

(Equation 1)

Equation 1 explains how, ($\frac{\dot{Y}(t)}{Y(t)}$), the growth rate of the growth rate of output (the acceleration rate) is determined by four microeconomic factors. Firstly, discount rates (ρ) affect the number of employees devoted to R&D since a higher interest leads to less patient employees and less investment in R&D (due to opportunity costs). Secondly, substitutability among the inputs used in R&D itself (ø). The higher the degree of substitutability the less workers engaged in R&D, in combination with slower productivity growth since in this case each input contributes less to output. Thirdly, the productivity of R&D (B), has a positive relation to growth. In addition, an increase in the productivity of R&D raises the willingness for workers to engage in that sector. Finally, an increase in population size ($\bar{L}$) automatically raises economic growth in the long-run since the model assumes that all individuals are engaged in either the production of intermediate inputs or in the production of R&D. Consequently, the number of employees devoted to R&D production is assumed to increase as the size of the population raises. Moreover, this also enlarge the returns to R&D since the larger the economy the more extended the market is for R&D, increasing its returns. In brief, all these microeconomic factors affect the number of workers devoted to R&D which in turn determines economic long-term growth.

However, the Romer model possesses certain drawbacks, firstly, by presuming only linear growth, and secondly, suggesting how advancements in R&D are merely an upsurge in the amount of inputs used in the production. Therefore, one might consider applying models put forward by Aghion and Howitt (1990), Grossman and Helpman (1991) as well as Jones (1995). Jones (1995) proposed a model permitting transition dynamics, thus the driving factor for growth in the long run is solely the growth rate of population. Aghion and Howitt (1990) and Grossman and Helpman (1994) alter how the technology process is defined, arguing how enhancements of prevailing inputs represent innovations. However, due to its simplicity, the regression in this thesis is based on Romer´s endogenous growth model (see equation 1), which furthermore, is the most well-known theory regarding R&D´s contribution to economic growth, making it an adequate basis for this paper.

On the other hand, other researchers find evidence of economic growth being the driving force of R&D which contradicts Romer´s model (see the next section, 3.2, for other researchers' findings). Romer (1990) places less focus on the possibility of GDP growth being a determinant of R&D expenditure instead of vice versa, implying that Romer´s model is of more importance examining our first research question (see section 3.3).

3.2 Related Literature

Previous research has diverse opinions on what is the predominant driver of economic growth. Capital accumulation and labour have been regarded as the most crucial factors influencing economic performance (Solow, 1957). Most researchers also stress the significance of technological change for improved living standards and economic development (Grossman & Helpman, 1994; Romer 1986, 1990; Solow, 1957). Investments in technology, specifically R&D, do not only benefit the private investor but the society as whole (Grossman & Helpman, 1994). Sørensen (1997) extends the argumentation by arguing that occasionally it is of relevance to subsidise areas such as R&D and education since these might result in economic growth. More recent studies from Huang and Lin (2006) as well as Raffo, Lhuillery and Miotti (2008) stress how knowledge inputs, specifically R&D, generally yield improvements in innovation, and thus impact economic growth positively. However, worth noticing is that the amount of R&D documented is merely a portion of what is spent on investments of new methods and goods, which therefore should be considered (Evenson & Westphal, 1995). Lastly, factors that might influence the level of R&D investments and economic growth more than policies and innovations are: institutions, laws, economic environment and mobility (Evenson & Westphal 1995; Grossman & Helpman, 1994; Pack & Westphal, 1986).

R&D investments are proved to have various outcomes despite the same amount invested, meaning that there is no simple model how to make R&D efficient (Pisano, 2012). Pisano (2012) also argues that the underlying mechanisms behind successful R&D investments are: the combination of the amount of labour and the level of skilled labour devoted to different production groups, the capacity and the headquarter of the R&D production, the technology used in the creation of R&D as well as the distribution of resources. Moreover, Pisano (2012) emphasises that companies do not perform equally well at all the components required for a profitable R&D investment, meaning that they all should have different strategies to increase R&D efficiency. This might be an explanation to why countries with different income levels experience various returns from R&D investments. For instance, Sørensen (1997) stresses that accumulation of education and skills should be the main priority when human capital is below a certain level. It is first after passing this hurdle it is beneficial for innovative activities and R&D, relating back to Pisano´s (2012) argumentation about the importance of skilled labour engaged in the R&D process.

Moreover, Sørensen (1997) concludes that less developed countries receive advantages of an open economy, due to technology spill overs. Grossman and Helpman (1994) highlight that a country should export the good in which they have a comparative advantage in, therefore countries with high human capital will have a head start in technology and will consequently export these goods in exchange for labour-intensive goods and for goods that do not demand the newest technology. These findings enlighten the importance of the type of technology used in the R&D production as well as the value of a company's geographical location, in theory with Pisano´s (2012) findings. This indicates that unequally wealthy countries should have different production strategies to R&D, due to their diverse specialization of industries.

However, not everyone agrees that R&D causes economic growth. Birdsall and Rhee (1993) conclude that it is not R&D that affects economic growth rather it is the vice versa. Furthermore, Bresnahan (1986) and Mansfield et al. (1977) argue that the amount of investments in commercial R&D is too small to impact economic performance. Moreover, R&D is proved to becomes less of a significant contributor to economic growth when a region possesses more advanced technology. Hence, R&D (as a factor of economic growth) is a non-linear function of already existing use of technology within a firm (Minniti & Venturini, 2017). Lederman and Maloney (2003) support this argumentation and stress that developing economies are mostly favoured of R&D returns. In addition, Brown and Svenson (1988) stress how managers generally do not measure their returns on R&D expenditure, in fear of receiving non-profitable results or since it is simply assumed to be a promising investment despite reasonable motives. This view is supported by Hall and Oriani (2006), concerning developed economies, arguing that European companies too rarely value its R&D investments.

3.3 Hypotheses

Summing up previous literature, providing different opinions regarding R&D´s impact on economic growth, brings motivation to the following hypothesis for research question 1:

- *R&D positively relates to GDP growth*

This hypothesis is tested by equation 3, presented in the empirical framework.

However, whether it is R&D that Granger causes GDP growth, or the other way around in different income classifications, is ambiguous, hence we test the following hypothesis for research question 2:

- *The Granger causality among R&D and economic growth is different in countries with diverse income levels*

This is tested by a Granger causality test and a Johansen's cointegration test in combination with the Toda-Yamamoto augmented Granger causality test (see equation 5, 6, 7 & 8).

4 Empirical Framework

The purpose of this chapter is to give a clear overview of: the data, model specifications and diagnostic tests and robustness tests.

4.1 Data

To investigate the proposed research questions data is gathered for the period 1996-2015 for a sample of 60 countries belonging to different income groups (see appendix A). This sample is collected allowing for five missing data points between 1996-2015 per variable and per country. The reason for allowing for five missing data points is a level effect in the R&D and corruption variables, meaning that countries either have approximately five missing data points or approximately ten missing data points, the lower alternative is therefore more appropriate. Moreover, the missing values is kept empty, meaning that we have an unbalanced panel data. Countries are thereafter divided into subsamples based on their income level, according to the income classification provided by the World Bank (2018c). The total sample of countries are, accordingly, divided into the following categories: high-income countries, upper-middle-income countries and lower-middle-income countries. Due to lacking data availability low-income countries are excluded from the analysis. These categories are based on the gross national income (GNI) per capita in current U.S. dollar, in which economies having a GNI per capita between $1,006-$3,955 are classified as lower-middle-income countries, economies with GNI per capita of $3,956-$12,235 are upper-middle-income countries and economies exceeding $12,235 being classified as high-income economies.

The main data source used is the World Bank, providing statistics for the variables in the production function: capital, labour and R&D, as well as the control variable trade. However, the World Bank does not provide information regarding the level of corruption within a country and therefore to obtain data for the Corruption Perception Index (CPI) Transparency International (The Global Anti-Corruption Coalition) is used.

4.2 Variables in the Econometric Analysis

To establish what drives economic growth, it is of relevance to establish which factors that have a significant relationship to it. As Solow (1957) concludes, it is not only capital and labour that are related to growth. The dependent and the independent variables are presented and justified below and a summary of the variables and how they are defined can be found in table 5.1.

GDP. To investigate what drives economic development (see equation 2 & 3), GDP growth is the dependent variable in the data set. It is established by market prices measured in the domestic currency and converted to U.S. dollar (The World Bank, 2018d).

Capital. Measured by gross capital formation, is based on the economy´s expenses on amendments regarding the fixed assets together with net alterations in the degree of inventories (The World Bank, 2018e).

Labour. Refers to individuals, of age 15 and above, supplying labour in production of goods and services. It considers both individuals employed and those searching for employment (The World Bank, 2018f).

R&D. Is the sum of public and private investment initiatives in innovating activities in technology as well as culturally and socially (World Bank, 2018a).

Trade Openness. Is the summation of goods and services being exported and imported, measured as a percentage of GDP (World Bank, 2018g). By specialising and exporting the goods and services in which a country has a comparative advantage, it will improve the country's economic performance (Grossman & Helpman, 1994).

Corruption. Here measured by CPI, ranks countries in the world from 0 (highly corrupt) to 10 (no corruption being present) based on the estimated level of corruption in the public sector. The ranking is based on opinions from: residents, experts within the field and outstanding observers (Transparency International, 2018). One would expect institutions and laws to positively affect economic growth (Evenson & Westphal, 1995; Grossman & Helpman, 1994; Pack & Westphal, 1986).

Table 4.1 Variables used on the regression model

Variables in the Regression Model			
	Description	Abbreviation	
Dependent Variable			
GDP growth	*GDP (Current US$)* Transformed by taking the natural logarithm and thereafter taking the first difference to correct for non-stationarity	ΔlnGDP	
Independent Variable			Expected Impact
Labour growth (%)	*Total labour force* Transformed by taking the natural logarithm and thereafter converting it into a percentage growth rate to correct for non-stationarity	glnL	+
Capital growth (%)	*Gross capital formation (Current US$)* Transformed by taking the natural logarithm and thereafter converting it into a percentage growth rate to correct for non-stationarity	glnC	+
R&D growth	*Research and development expenditure (% of GDP)* Transformed by taking the natural logarithm of the absolute value and thereafter taking the first difference to correct for non-stationarity	ΔlnR&D	+
Trade openess	*Trade (% of GDP)* Transformed by taking the natural logarithm	lnTO	+
CPI	*Corruption Perception Index*	CPI	-

See appendix B for ADF unit root test on variables

4.3 Empirical Model of R&D´s Relation to GDP Growth

The data is plotted to validate a linear relationship among the variables. To control for extreme outliers a robustness test, using winsorization, is conducted on all the variables before the model is specified. Winsorization is conducted at the 0.5% level, meaning that outliers above or below the 0.5th percentile are removed to receive the value of the 99.5th percentile. Moreover, White´s cross-section standard errors and covariance is used to regard potential problems with heteroscedasticity within the cross-sections, which furthermore is applied for all models estimated. In addition, all regressions are tested at the 5% significance level.

4.3.1 Model Specifications

The Solow Growth model provides a fundamental basis in economic development theories, and hence, provides a starting point for the analysis. Therefore, the first model includes only the variables capital and labour in explaining economic performance. However, non-stationary variables have time-varying mean and/or variance meaning that they are improper for forecasting. Hence the unit root test Augmented Dickey Fuller (ADF) test is conducted on the variables. This results in capital and labour being converted into percentage growth rates.

$$\Delta lnGDP_{it} = \alpha_1 + \beta_1 glnC_{it} + \beta_2 glnL_{it+} \upsilon_{it}$$

(Equation 2)

To extend equation 2 further towards Romer´s (1990) proposition of R&D and technology as a significant factor to economic growth, R&D as well as two control variables: trade and corruption are added. Furthermore, an ADF test indicates undesirable patterns in the variables trade and R&D, while corruption is stationary in its original form (see appendix B for unit root tests on all variables). Therefore, the variables GDP and R&D are transformed to growth rates by taking the first difference, lastly, trade is replaced by trade openness. This does not only correct for non-stationarity but also for multicollinearity, which otherwise would have been present among R&D and trade in absolute terms (see appendix C for correlation matrix).

$$\Delta lnGDP_{it} = \Theta_1 + \delta_1 glnC_{it} + \delta_2 glnL_{it} + \delta_3 \Delta lnR\&D_{it} + \delta_4 lnTO_{it} + \delta_5 CPI_{it} + \varepsilon_{it}$$

(Equation 3)

Equation 3 is adjusted and tested using a pooled ordinary least squares (OLS), random effects model (REM) and a FEM. To determine the appropriate model, one tests the pooled OLS and FEM against each other using a redundant fixed effects test. Rejecting the null hypothesis, H0: Pooled OLS is appropriate, one can conclude that FEM is preferable (see appendix D). Furthermore, a Hausman test is conducted to conclude whether a FEM or a REM is appropriate. Moreover, this test additionally concludes that FEM is preferable, thus rejecting the null hypothesis of REM being the appropriate model (see appendix E). Thus, the FEM is specified as follows:

$$\Delta lnGDP_{it} = \mu_1 + \lambda_1 glnC_{it} + \lambda_2 glnL_{it} + \lambda_3 \Delta lnR\&D_{it} + \lambda_4 lnTO_{it} + \lambda_5 CPI_{it} + \nu_t + \omega_i + \eta_{it}$$

$$i = country\ 1,2,\dots,60$$

$$t = time\ 1996, 1997, \dots, 2015$$

$$\nu_t = year\ dummies$$

$$\omega_i = country\ specific\ fixed\ effect$$

(Equation 4)

The FEM holds both cross-sections (countries) and period (time) fixed, meaning that the slope coefficients are equal across countries, but with different intercepts which varies over time (Gujarati & Porter, 2009).

4.4 Empirical Model of Causality

For the FEM to be unfaltering all explanatory variables need to be exogenous. As depicted in appendix F, the R&D variable is not exogenous when conducting a Wald´s test, meaning that there are problems with endogeneity in the independent variable R&D, causing the FEM to be less useful for estimating and especially inappropriate in forecasting (Gujarati & Porter, 2009). To consider this, a Granger causality test and the Toda-Yamamoto approach in combination with Johansen's cointegration test are conducted.

Granger (1969) emphasises the relevance of the direction of causality among variables examined. Even though a significant relationship can be established among the variables it does not prove the direction of the causality between them. The basic intuition behind the Granger causality test is that if one occurrence befalls before another, the initial event may influence the latter, but not vice versa (see equation 5 and 6). This test assumes the variables to be stationary and error terms to be uncorrelated. However, transforming non-stationary variables by taking the first difference deteriorate the long-term relation among the regarded variables (Granger, 1969). Further drawbacks are non-validity concerning non-linear and instantaneous relationships. Also, seasonality effects can cause misinterpretation of causality if they are not considered. For instance, public holidays such as Christmas, is the reason to why the sale of toys, Christmas food and other gifts associated with Christmas increase and not vice versa, meaning that the basic intuition behind the Granger causality does not always hold (Granger, 1979). Moreover, the Granger causality test requires the variables to be integrated of the same order. Since, the variables R&D and GDP are in their first difference, the variables fulfil the criterion of same integration order, in this case integrated of order one. Furthermore, Schwarz criterion and Akaike information criteria are used to determine the optimal lag length for each individual income group. However, since this test is incapable of measuring the long-term relationship between two variables, it is only used for examining the short-run influence.

$$\Delta lnGDP_t = \sum_{i=1}^{n} \alpha_i \, \Delta lnR\&D_{t-i} + \sum_{j=1}^{n} \beta_j \Delta lnGDP_{t-j} + u_{1t}$$

(Equation 5)

$$\Delta lnR\&D_t = \sum_{i=1}^{n} \lambda_i \Delta lnR\&D_{t-i} + \sum_{j=1}^{n} \delta_j \Delta lnGDP_{t-j} + u_{2t}$$

(Equation 6)

Where ΔlnGDP is the first difference of absolute GDP in natural logarithm, ΔlnR&D is the first difference of absolute R&D expenditure in natural logarithm (see table 4.1), i and j is the optimal lag lengths and the u is an error term.

Toda and Yamamoto (1995) enlarge the Granger causality testing by bringing forth an approach that is appropriate regardless of whether the data is stationary, non-stationary (and not cointegrated) or cointegrated. The test is built on a vector autoregressive (VAR) model based on the levels of the data regarded, meaning that the data is run in its original form (see equation 7 and 8). The number of lags included is determined from information criteria, which furthermore, is required to be extended by one additional lag to examine whether the model is dynamically stable. This approach is based on Granger causality; however, it does not deteriorate any long-term relationship suggesting a useful complement to the original Granger causality test. Hence, to regard the longer direction of Granger causality the Toda-Yamamoto approach is exercised. Moreover, for the Toda-Yamamoto´s Granger causality results to be equivalent to Johansen's cointegration test, the variables must exhibit a significant direction of Granger causality and simultaneously be cointegrated, or be insignificant with no cointegration present, otherwise there is a substantial indication of conflicting results.

Since this approach has no restrictions regarding order of integration, one does not have to correct the variables for non-stationarity for this test to be valid, hence the variables are tested in their original form.

$$\Delta GDP_t = \alpha \sum_{i=1}^{h+d} \beta_i \Delta GDP_{t-i} + \sum_{j=1}^{k+d} \gamma_j R\&D_{t-j} + u_{yt}$$

(Equation 7)

$$R\&D_t = \alpha + \sum_{i=1}^{h+d} \theta_i R\&D_{t-1} + \sum_{j=1}^{k+d} \delta_j \Delta GDP_{t-j} + u_{xt}$$

(Equation 8)

Where ΔGDP is the first difference of the absolute GDP (since the purpose is to examine the relation of R&D expenditure and GDP growth, and not R&D expenditure´s relation to GDP in absolute terms), R&D expenditure is in absolute terms, h and k are the optimal lag lengths of GDP growth and R&D, d is the maximal order of integration and u is an error term, assumed to be white noise.

4.4.1 Additional Diagnostic Tests and Robustness Tests

A Jarque-Bera normality test is conducted to detect undesirable patterns in the residuals. Conducting this normality test for all income groups, one can conclude that the residuals are non-normally distributed for the high-income group and the upper-middle-income group. Whereas, for the lower-middle-income the residuals are normally distributed (see appendix G for all normality tests).

5 Empirical Results and Analysis

The purpose of this chapter is to provide the reader with an extensive analysis regarding R&D relation to economic growth and in which direction the causality exists.

5.1 Analysis of R&D´s Relation to GDP Growth

To investigate the first research question a FEM is conducted on equation 3, symbolising (3) in table 5.1. Thus, table 5.1 depicts outcomes for the aggregated panel regression for the timespan 1996-2015. The Durbin-Watson statistic is rather close to two, meaning that most likely there are no problems with autocorrelation. Analysing the fundamental variables capital and labour one can observe immense discrepancies, capital growth is statistically significant whereas labour growth is insignificant for all models, meaning that capital growth relates to the expansion in GDP whereas, labour growth does not. Capital has long been known to be the main source to economic growth (Solow 1956, 1957), hence the positive significant result is expected. The control variable corruption has the expected sign; however, it is not significant at the 5% significance level when controlling for period and cross-section in the FEM, on the other hand, observing the standard errors one can conclude that it is not far from significance. The control variable trade openness has a negative effect on GDP growth in the FEM.

Table 5.1 Modelling GDP growth on its determinants

Modeling GDP Growth on its Determinants		
	FEM	
Independent Variables	(2)	(3)
Intercept	0.0014*	0.0122*
	(0.0001)	(0.0121)
Capital growth	0.3658*	0.3580*
	(0.0104)	(0.0121)
Labour growth	0.0418	0.0675
	(0.1032)	(0.1038)
R&D growth	-	0.0016*
		(0.0006)
Trade openess	-	-0.0021*
		(0.0007)
CPI	-	-0.0003
		(0.0002)
Nr. of observations	1198	956
Durbin-Watson	1.8944	1.8168
R-squared	0.7494	0.7676

* indicates that p-value < 0.05
Standard errors in parenthesis, estimated using White´s cross-section standard errors and covariance estimator

Lastly, focusing on the R&D variable, the FEM indicates that growth in R&D expenditure has a positive relationship to economic growth when aggregating all countries in the sample, which is supported by Grossman & Helpman, (1994), Romer (1986, 1990) and Solow, (1957). This aspect is additionally touched upon by more recent studies (Huang & Lin, 2006; Raffo, Lhuillery & Miotti, 2008). However, the coefficient of R&D in the FEM is 0.001609 percent, implying that R&D growth has a relatively small relationship to economic development, on the other hand, the true value of R&D investment is only a small fraction of all investment initiatives taken regarding new development (Evenson & Westphal, 1995). This could be an explanation to the relatively low coefficient of the R&D variable. On the other hand, since R&D growth is not strongly (or even weakly) exogenous, these results are generally not fully accurate, meaning that it is not of relevance to extend this model further, or applying it on the different income groups. However, this enlightens the importance of our second research question examining the direction of Granger causality among the regarded variables.

5.2 Analysis of Causality

One can conclude that R&D growth Granger causes GDP growth for all income levels during the time span 1996-2015 using the Granger causality test (see table 5.2). This test represents the short-term relationship, implying that R&D growth is a determinant of economic growth in the short-run regardless of income level. This result is rather unexpected, since one would expect GDP growth to influence growth in R&D expenditure in lower-middle-income countries due to less wealthy economies (Goni & Maloney, 2014). However, the results for the two remaining income groups, high-income and upper-middle-income are as expected, stressing that R&D growth Granger causes GDP growth (Romer, 1990). Furthermore, UNESCO (2015) emphasises how lower-income economies and middle-income economies invest in R&D in an attempt to create a sustainable strategy for growth to raise income levels and better the welfare, while, high-income economies invest mostly in R&D to stay competitive on the global market.

Table 5.2 Results of Granger causality tests on income groups 1996-2015

Granger causality and Toda-Yamamoto Granger causality on different income groups						
	Short Run (Granger causality)			Long Run (Toda-Yamamoto approach)		
	R&D Granger GDP growth	GDP growth Granger causes R&D	Nr. of obs.	R&D Granger causes GDP growth	GDP growth Granger causes R&D	Nr. of obs.
All Income Levels	7E-15*	0.6487	968	0.0649	0.7227	528
High-Income	2E-7*	0.1025	546	0.1021	0.3221	438
Upper-Middle-Income	6E-5*	0.8464	306	0.1326	0.2531	170
Lower-Middle-Income	4E-3*	0.6737	116	0.6692	0.7345	102

* indicates that p-value < 0.05
Values displayed are p-values

However, these empirical results might illuminate the so-called R&D-paradox, meaning that developed countries tend to invest in R&D regardless of the final outcomes, on account of, partly national policies (public R&D) but predominantly private R&D investments (Brown & Svenson, 1988; Hall & Oriani, 2006). On the other hand, this does not mean that R&D is not providing higher-income countries with productive advantages, simply that less wealthy countries are catching up, receiving relatively larger benefits of its R&D expenditure, which is supported by UNESCO (2015) presented in the background chapter. In short, even though one can observe a direction of Granger causality from R&D growth to economic growth, one cannot measure to what extent it is profitable to invest in R&D, meaning that high-income economies might overinvest in R&D compared to what is efficient.

Further explanations to the results can be based on firms´ choice of location, indicating the importance of the different production strategies to obtain efficient R&D investments, among different countries (Pisano, 2012). For instance, multinational firms choose to invest in R&D in high-income countries but the production itself is accomplished in countries with less expensive capital and labour force, meaning that those countries reap the predominant benefits of R&D investment. This is supported by Grossman and Helpman (1994) and UNESCO (2015). Grossman and Helpman (1994) enlighten the basics behind trade theory, essentially countries should export what they have a comparative advantage in. Higher-income economies usually have knowledge-intensive advantages and hence invest in R&D whereas lower-income countries generally possess labour-intensive advantages resulting in the production of the inventions. This also relates to the level of education among different countries. Lower-income economies generally have less educated populations indicating that they should have a different approach to increase their R&D profitability (Pisano, 2012). As Sørensen (1997) argues it should be a main priority to invest in human capital since it is first after the lower-income economies have reached a sufficiently high level of education that it is beneficial for them to invest in R&D. However, in our results we can observe that R&D growth Granger causes GDP growth also for the lower-middle-income group, indicating that this income group has either a sufficiently educated population or benefits from technology spill overs from more developed economies.

Furthermore, when considering the Toda-Yamamoto augmented Granger causality test one cannot observe the direction of the relationship in the period 1996-2015. This approach considers the long-term, implying that the direction of Granger causality among R&D expenditure and economic growth is unestablished. This result contradicts the results expected, believing that R&D investment would be a determinant in economic growth for the high-income and upper-middle-income countries and vice versa regarding the lower-middle-income group. However, worth mentioning is that when considering the Granger causality for all income groups aggregated, the p-value is close to significant (approximately 0.06), meaning that R&D expenditure Granger causes economic performance in the long-run at the 10% significance level.

Moreover, we have a conflict in the results in all income levels in which Johansen's cointegration test indicates cointegration between the variables, meaning that one should observe a Granger causality between the variables in at least one direction, however, the Toda Yamamoto procedure does not indicate any long-run relationship. These contradicting results may rise from our relatively short time span, which deteriorates the test´s reliability (Toda and Yamamoto, 1995) or since some of the p-values are relatively close to significance, it implies that the Toda-Yamamoto approach might not have conflicting results with Johansen's cointegration test testing at a higher significance level i.e. 10%.

6 Conclusion

This chapter summarises the paper with focus on the main findings, the limitations of the analysis conducted, contributions to society and future research possibilities.

The purpose of this paper is to firstly, investigate whether R&D is positively related to GDP growth, and thereafter, analyse the direction of this relationship in different income levels, looking at Granger causality in the short-run as well as the long-run. This is conducted using panel data consisting of 60 countries over a period of 20 years, from 1996-2015. The data is mainly collected from the World Bank, however, Transparency International (The Global Anti-Corruption Coalition) is also used.

The results in this paper display a positive relationship between GDP growth and the growth of R&D expenditure, using a FEM allowing for country specific intercepts varying over time. The strength of their relationship is somewhat lower than expected, with a possible explanation of R&D being only a fraction of all initiatives taken in creation of new goods and methods. Furthermore, the R&D variable seems to be endogenous in the model, meaning that whether R&D growth drives economic growth or vice versa is less straightforward. The Granger causality tests show, however, that on short-term basis, the growth of R&D expenditure has a positive impact on GDP growth regardless of income level. One might have expected GDP growth to Granger cause R&D growth for the lower-middle-income group due to its inferior economic benchmark. A reasonable motivation to this might be the underlying mechanisms behind efficient R&D, for instance, where multinational corporations choose to geographically place their production, since this influence where the benefits of R&D are ultimately reaped. Further explanations can be the level of educated people within different income groups, meaning that they face different strategies to increase R&D productivity. Moreover, considering the long-run results no clear conclusion can be ascertained to whether it is R&D expenditure that Granger causes economic development or vice versa. Conflicts between Johansen's cointegration test and the Toda-Yamamoto procedure exist, meaning that no accurate conclusions can be drawn. A possible explanation for the conflicting results might be the length of the time span, meaning that it might not be long enough for what is required for the Toda-Yamamoto approach to provide credible results.

R&D growth is, in this paper, proved to Granger cause economic growth in the short run irrespective of income level. This implies that R&D adds value to a country's economic development regardless of whether countries are classified as developed or emerging, meaning that also lower-middle-income economies benefit from investments in R&D. The dimensions of the R&D-paradox are still unrequited, meaning that it is difficult to measure if developed countries overinvest or efficiently deposit capital in R&D. Despite the ambiguities, R&D investments stimulate economic growth and should, to some extent, be favoured by policy regardless of a nation's level of development.

A limitation of the study is the data availability of R&D expenditure as a percentage of GDP, not only for individual countries but also for the timespan, in which only 1996-2015 is available. As data collection develops one can exploit all income levels and hence, future researchers can utilise the better data availability and therefore develop studies regarding R&D in countries with lower income. Moreover, as time progresses the time span investigated could be extended and can therefore better account for the long-term effects of R&D. Another limitation is that inflation is not accounted for in the model. Moreover, savings is not considered in the regression when modelling GDP growth on its determinants, due to its lacking data availability.

Suggestions for future research studies are, to investigate which underlying factors that cause R&D productivity and therefore GDP growth. Moreover, it would be of interest to combine R&D with policies and regulations in for instance an interaction term and thus, investigate whether different policies and regulations of dissimilar countries cause a multiplier effect of R&D on GDP growth.

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Appendices

Appendix A – Country list with income groups and average R&D expenditure

Country list per income group with average R&D expenditure (%)

Average R&D Expenditure (% of GDP) per Country With Countries Divided According to Income Levels							
High-Income				Upper-Middle-Income		Lower-Middle-Income	
Austria	2.500	Korea, Rep.	3.142	Argentina	0.494	Armenia	0.249
Belgium	2.044	Lithuania	0.802	Azerbaijan	0.243	Egypy, Arab Rep.	0.413
Canada	1.879	Latvia	0.540	Bulgaria	0.543	India	0.771
Cyprus	0.378	Netherlands	1.819	Belarus	0.674	Kyrgyz Republic	0.177
Czech Republic	1.394	Norway	1.626	Brazil	1.072	Moldova	0.422
Germany	2.601	Poland	0.687	China	1.481	Tajikistan	0.093
Denmark	2.708	Portugal	1.105	Colombia	0.185	Ukraine	0.881
Spain	1.161	Singapore	2.115	Cuba	0.496	Uzbekistan	0.238
Estonia	1.251	Slovak Republic	0.641	Ecuador	0.243		
Finland	3.355	Slovenia	1.803	Croatia	0.857		
France	2.140	Sweden	3.389	Kazakhstan	0.208		
United Kingdom	1.639	Trinidad and Tobago	0.079	Mexico	0.446		
Greece	0.656	Uruguay	0.335	Macedonia, FYR	0.287		
Hungary	1.070	United States	2.661	Panama	0.219		
Ireland	1.325			Romania	0.438		
Iceland	2.531			Russian Federation	1.120		
Israel	4.102			Serbia	0.661		
Italy	1.162			Thailand	0.300		
Japan	3.178			Turkey	0.702		

(Source: The World Bank, 2018a)

Appendix B – Augmented Dickey-Fuller unit root test

H_0: Unit root (non-stationary)

H_1: No unit root (stationary)

Augmented Dickey Fuller unit root test on variables

Augmented Dickey-Fuller Unit Root Test												
Before correction	GDP		Capital		Labour		R&D		Trade		Corruption	
Method	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
ADF - Fisher Chi-square	146.165	0.0403	100.466	0.9020	102.364	0.8761	85.3057	0.9930	51.3302	1.0000	207.556	0.0000
ADF - Choi Z-stat	1.25703	0.8956	1.79575	0.9637	3.29355	0.9995	4.85327	1.0000	6.52091	1.0000	-4.91826	0.0000
After correction	GDP growth		Capital growth (%)		Labour growth (%)		R&D growth		Trade openess			
Method	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.		
ADF - Fisher Chi-square	181.721	0.0002	330.941	0.0000	376.040	0.0000	291.917	0.0000	172.487	0.0012		
ADF - Choi Z-stat	-4.17100	0.0000	-9.89178	0.0000	-10.1114	0.0000	-8.25889	0.0000	-2.13854	0.0162		

All variables are in natural logarithms

Appendix C – Correlation matrix

Correlation matrix of variables in regressions

Correlation Matrix of Variables								
	ΔlnGDP	glnC	glnL	lnR&D	ΔlnR&D	lnT	lnTO	CPI
ΔlnGDP	1	0.8202	0.1310	-0.2108	0.3013	-0.1732	0.0769	-0.2147
glnC	0.8202	1	0.1346	-0.1534	0.2613	-0.1261	0.0645	-0.1468
glnL	0.1310	0.1346	1	-0.1027	0.0759	-0.0571	-0.0144	0.0259
lnR&D	-0.2108	-0.1534	-0.1027	1	-0.1300	0.9299	-0.3207	0.5435
ΔlnR&D	0.3013	0.2613	0.0759	-0.1300	1	-0.1057	0.0306	-0.1201
lnT	-0.1732	-0.1261	-0.0571	0.9299	-0.1057	1	-0.2173	0.4998
lnTO	0.077	0.0645	-0.0144	-0.3207	0.0306	-0.2173	1	0.1474
CPI	-0.2147	-0.1468	0.0259	0.5435	-0.1201	0.4998	0.1474	1

Appendix D – Redundant fixed effects test

H_0: Pooled OLS is preferred

H_1: Pooled OLS is not preferred (FEM is appropriate)

Redundant fixed effects test determining whether pooled OLS or FEM is appropriate.

Redundant Fixed Effects Test			
Test cross-section and period fixed effects			
Effects Test	Statistic	d.f.	Prob.
Cross-section F	1.0996	-59.884	0.2874
Cross-section Chi-square	68.4841	59	0.1865
Period F	14.4692	-18.884	0.0000
Period Chi-square	249.6969	18	0.0000
Cross-Section/Period F	3.9339	-77.884	0.0000
Cross-Section/Period Chi-square	284.9275	77	0.0000

Appendix E – Hausman test

H_0: REM is preferred

H_1: REM is not preferred (FEM is appropriate)

Hausman test determining whether REM or FEM is appropriate.

Hausman Test			
Test period random effects			
Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Period random	28.9598	5	0.0000

Appendix F – Wald´s test

H_0: No endogeneity (exogenous)

H_1: Endogeneity

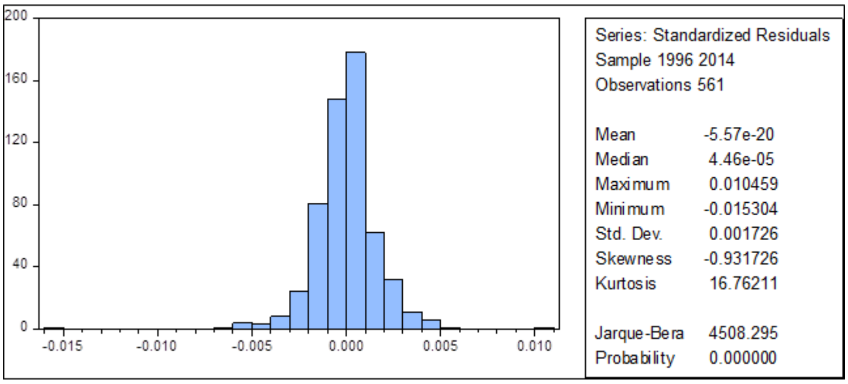
Wald´s test of endogeneity on R&D growth

Wald´s test			
Test Statistic	Value	df	Probability
t-statistic	2.5799	884	0.0100
F-statistic	6.6557	(1, 884)	0.0100
Chi-square	6.6557	1	0.0099

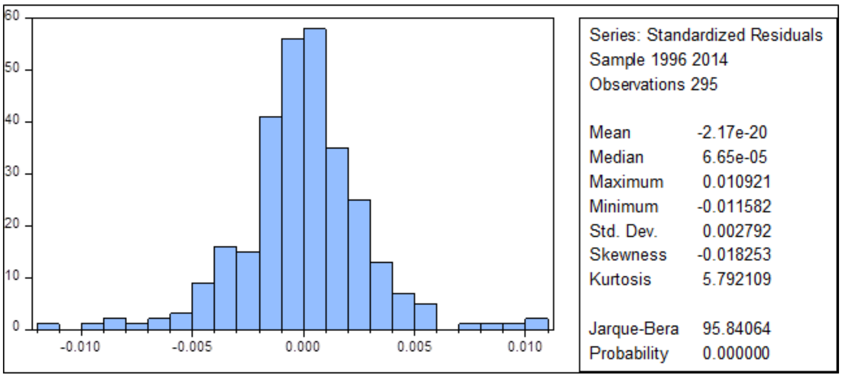
Appendix G – Jarque-Bera normality test

H_0: Normally distributed residuals

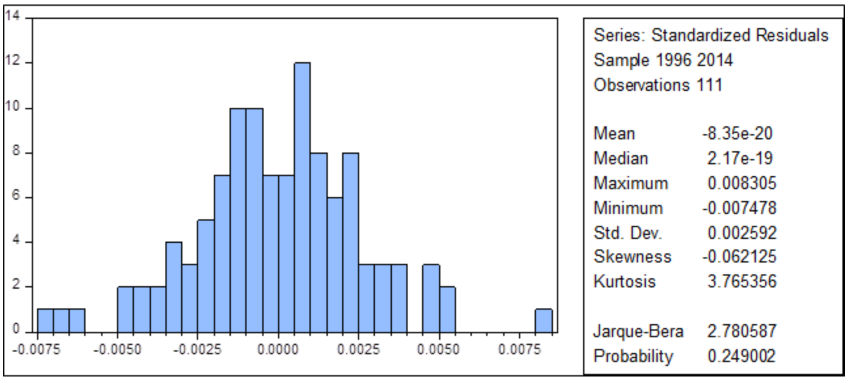
H_1: Non-normally distributed residuals



Jarque-Bera normality test for high-income group 1996-2015.



Jarque-Bera normality test for upper-middle-income group 1996-2015.



Jarque-Bera normality test for lower-middle-income group 1996-2015.