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How can innovation contribute to economic growth?

Focusing on research productivity and the commercialisation process

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Abstract

The aim of this thesis is to give a clearer empirical picture of innovations and its connection to economic growth. As a point of departure we use an endogenous growth model, the Romer model, to theoretically develop this connection. This is shown through a modified equation for accumulation of technology. The model was extended with a modified variable for research productivity and a new variable for commercialisation. The variables are represented with indexes constructed from an econometric regression. As dependent variables we have used patent for the productivity index and newly started businesses for the commercialisation index. Using data from 16 European countries we have identified variables that affect our dependent variables. To find empirical measurements for economic variables in theoretical models is important for the models' utility. With this thesis we want to show that both the political and academic discussion on innovations and economic growth would profit from also focusing on research productivity and commercialisation of innovations.

Keywords: innovation, research productivity, commercialisation, the Romer model, multiple regression, panel data.

Table of contents

1 Introduction 1

1.1 Point of depature and background 1

1.2 Purpose and problem area 2

1.3 Method and material 3

1.4 Disposition 3

2 Innovations as the engine of economic growth 5

2.1 Innovation and economic growth 5

2.2 Productivity in the R&D sector 7

2.3 Commercialisation of technology 8

3 The Romer model with innovation 10

3.1 The basic Romer model 10

3.2 The extended model 12

3.2.1 Technological change 12

3.2.2 Steady state 15

4 Econometric framework 18

4.1 Multiple regression 18

4.1.1 The OLS regression 18

4.2 Panel data 20

4.2.1 Fixed or random effects 21

4.3 Data and variables 22

4.3.1 Index for productivity 23

4.3.2 Index for commercialisation 26

5 Empirical findings 28

5.1 Methodological considerations 28

5.2 Regression output for productivity 29

5.3 Regression output for commercialisation 31

6 Analysis and final words 33

6.1 Analysis 33

6.1.1 The expanded theoretical model 33

6.1.2 Econometric and empirical analysis 35

6.2 Final words 39

7 Referenser 42

8 Appendix 44

8.1 Appendix A 44

8.2 Appendix B 48

8.3 Appendix C 49

1 Introduction

1.1 Point of depature and background

In the last century developed economies such as the US or European countries have faced a high economic growth rate (Fregert & Jonung 2003 p 158). This growth has in large been caused by the growth of knowledge and innovation, in comparison to earlier in the history when it were natural resources or labour that caused a higher growth. In the Lisbon summit in 2000, the heads of the EU countries agreed that innovation policies must play a central role in future growth policies (Vinnova 2002 p 6). Innovation and economic growth seem to have a connection and clearly there are lots of activities going on both in the EU as well as in other parts of the world with the purpose to encourage innovations. The connection between innovations or technology and growth is something that has been studied for some time even though the concept innovation has not been used that frequently (OECD 2008 p 29-30). We want to continue this work by developing an already existing endogenous growth model in a way for it to better describe how innovation affects the economic growth.

The Romer model is one of the endogenous growth models where the growth in the model is depending (among other things) on the level of technology and the growth rate at which new ideas are developed. Studying the connection between technology, innovations and economic growth in both a theoretical and in an empirical way we got interested in finding out what affected the growth rate at which innovation is created i.e. the productivity of innovations. Is it the structural settings that affect the growth rate of innovation? Clearly there are some countries like the US or Sweden that invest a lot of money and effort in raising the growth rate of the creation of innovations. Sweden is one of the countries in the world that uses the largest share of GDP on research and development (R&D), but the economic results from the R&D are not at the same level as in countries like the US (Vinnova 2003 p 3). The US seems to have a clearer connection between innovation and economic growth. So, why is that? What affects the rate at which innovations lead to economic growth, i.e. the commercialisation of innovations?

When studying innovations we have focused on developed countries and brought up some particular examples from Sweden since it is a country were innovations have been encouraged but were the commercialisation process is not very well-developed – an interesting case we think. In the field of study of innovations and economic growth there seems to be several objects to study, and our intension is to contribute to further understanding.

1.2 Purpose and problem area

With the discussion above in mind these problems raised our curiosity, innovations and growth - is there a connection? And if so how strong is it and what does it look like? Those were questions that led us in to this thesis' problem area. In the following essay we have the intention to describe what factors affect the production of innovation in a country, for example how well educated the population is or how developed the soft infrastructure is. We will not show the statistical connection between innovation and economic growth. This is something that has been studied by a lot of researchers before and therefore we think it is more interesting to highlight the factors that have a positive connection to, or that is an important factor for the growth at which innovations are generated - an index for the productivity of the creation of innovations.

Further it would be interesting to study why some countries are better at getting the innovations to affect the economic growth. What makes countries such as the US better than Sweden at putting successful innovations on the market? In this study we therefore also want to find the factors that are important to the commercialisation process - an index for commercialisation of innovations.

Our purpose is moreover to investigate the theoretical work to give our index another dimension. We therefore expanded an endogenous growth model, the Romer model to include our index which would affect the technology growth and the economic growth.

We will conduct two regressions in which from which we will identify factors that affect the productivity of innovation and also the commercialisation of innovations. We also want to include the two indexes that we constructed through the regressions, into the Romer model, with the purpose of studying how these indexes could affect the economic growth. Our contribution to research is mainly that we find variables that could be empirically measured and fitted into a model. Our main purpose is to give a clearer empirical picture of innovation and its connection to economic growth.

The following questions are the foundation on which our thesis is based.

- What is important for the productivity of the creation of innovations?
- What is important for the commercialisation of innovations?
- How do the productivity of innovations and the commercialisation process of innovations affect the economic growth in the Romer model?

1.3 Method and material

As stated above, the main purpose of our study is the explanation and development of the two indexes and the following expansion of an economic growth model. As a theoretical foundation we use the Romer model and extend it to include our indexes for productivity and commercialisation, which is explained in chapter three. The regression is constructed as an OLS-regression and estimated in the program Eviews. The econometric methods used are further examined in chapter four.

Our material consists mainly of research articles concerning innovation and economic growth. It also contains reports from different research institutes and authorities like Vinnova and ISA (Invest in Sweden Agency). The data used in the regression is collected from different research institutes, mainly Eurostat but also the World Development Indicators (WDI) and the OECD databases.

1.4 Disposition

In the following chapters we will answer the questions that we presented in the purpose and problem area section. To do so we start with a chapter of the connection between economic growth and innovations and continue with a discussion about the productivity in the R&D sector and also the commercialisation of technology or innovation, that is our indexes. In chapter three we have our theoretical chapter where we describe and discuss the Romer model with innovation. In this chapter we show the basic model and also an expanded model where we have included our indexes. This chapter also contains the mathematical development of the model. In chapter four we describe the method of the study, the econometric framework. We describe how we constructed the regressions, which tests and corrections we made and also which variables that we choose for the regression. After that we have a chapter with the result numbers and tables from the regression, our empirical findings. In chapter six we have the analysis and some final words, where we discuss our regressions' results and also the expanded model. In the sixth chapter we also discus ideas for further research. Finally, there is a list of references and the appendixes.

2 Innovations as the engine of economic growth

This chapter is aimed to give a theoretical background to the connection between innovations and economic growth. This is to give an understanding of the forthcoming choice of economic growth model and to the choice of empirical study. The relation between innovations and economic growth, the importance of productivity and commercialisation are topics that will be examined in this chapter.

2.1 Innovation and economic growth

Economic growth is an increase of the production capacity for the things that produces for final use of the economy, an increase in the GDP. The growth rate will always be expressed as the percental increase of GDP over a certain time period (Hansson 2009 p 1).

Before it is possible to measure innovation we have to have a definition of what innovation is at hand. “Innovations, that is new products, services and processes, form the basis for sustainable growth and prosperity in a knowledge-based society” it is written in a Vinnova report from 2002 (Vinnova 2002 p 6). A problem measuring innovation is that it per definition is novelty. The creation of something qualitatively new, comes from the process of learning and knowledge building (Smith 2005 p 149). Important factors for the development of innovation are skills, the exchange of knowledge and also collaboration and interaction between companies, research institutions and political bodies. The better those factors work together the more efficient the generation of innovations and its contribution to economic growth can be (Vinnova 2002 p 6). To encourage innovation, one important component is investments in R&D, which has become one of the most important issue in policies for growth and prosperity in many OECD countries (Vinnova 2002 p 6). In the literature the words innovation and technology are used in a similar way. The word technology mainly focuses on an invention in the technical field. We will most often use the world innovation when describing the novelty, but when the literature uses technology with the same understanding we will use that word instead.

The developed economies today are increasingly based on knowledge and innovation. In the knowledge-based economy the emphasis on knowledge as the driver of economic growth is evident. Focus is set on the role of information, technology and learning. The emergence of the information society has contributed with improved ways for distribution of innovations through communications such as the Internet (OECD 1996 p 1 &7). Since the late nineties governments around the world have emphasized the importance of a knowledge-driven economic growth (Vinnova 2003 p 42). In the Vinnova report from 2003 it says that 25–50 percent of the economic growth in the OECD countries is a result of new technology (ibid p 75). In the report it is also drifted that universities, at least in the US, are the engines of the innovation system and therefore also the engines of the economic growth (ibid p 81). Technology has become the most valuable production asset in the industrialised countries of the world (ISA 2003 p 18)

The industrialised countries are today standing in front of a major reconstruction of the production structures, they are on the doorstep to a "new economy" (ISA 2003 p 6). Today there is a rapid technological development going on, where the geographical distance is of less importance, and because of that the global competitiveness increases (ibid p 3). Growth is about investments in a broad sense – investments in new technology as well as in competence in the population, i.e. human capital (ibid p 21). As stated before, the new technologies for communication have also fastened up the globalisation of production and this can also be defined as a part of a new economy (ibid p133).

In the endogenous growth model (which we will describe further in chapter three) innovation and technology are the drivers of economic growth. In this economy the human capital is of great importance for the development. We have chosen to use and further develop the Romer model in our way to link economic growth to innovations. The purpose of using this model would be the focus that the model puts on the technology and production of innovation. This model also focuses on the part of the population that is working in the R&D sector and the importance of the human capital in a broad sense. That is also what we are interested in studying, the connection between innovation and economic growth. In that case this is a very useful model.

Innovation and technology will not per automatic be the only part of economic growth, but in our knowledge-based globalised economy those are the main factors that will create and continue to affect the economic growth.

2.2 Productivity in the R&D sector

If innovations are a key to economic growth it is possible to believe that a country would want to come up with as many innovations as possible. By investing money in R&D they hope that more innovations will be generated from that sector. However larger expenditure on innovations does not automatically lead to more innovations. Since a large amount of capital is invested in the research sector every year it is important to study the productivity of that sector (Adams & Griliches 1996 b p 1).

To study the productivity in the R&D sector is important since this basic research conducted in this sector is key to industrial innovation (Adams & Griliches 1996 p 1). If the productivity in the research sectors declines, the input to industrial research would decrease and new ideas and products would emerge less frequently (ibid). To see what output research generates is both interesting from an economic and a development perspective (Adams & Griliches 1996 b p 1). However, measuring productivity is not done without complications (ibid p 2).

To get a cohesive picture of the overall productivity of the R&D sector and thus what affects the rate of technological change is as said earlier not easy. There is no suitable and evident measurement at hand which would cover up this wish to give an all-embracing illustration of the productivity and technological/scientific progress (Griliches 1990 p 1661). Therefore, we have to accept the fact that what we can do is only to try and find an indicator that is related to the phenomenon we want to study. The productivity of academic research is sometimes explained by studying the number of publications of research results (Vinnova 2003 p 43). However, it cannot be argued that journal publications really mirror the technological progress. Our saviour in this particular case is patent statistics (Griliches 1990 p 1661). Data cover for patent statistics is good and it is clearly linked to inventiveness (ibid). Patent can be defined as a document that is issued by an authorised agency which will grant the right to exclude anyone else from use or production of the invention that is patented. The patent is granted based upon the novelty and the utility of the invention (ibid p 1662). When a research result or an idea result in a patent application it is an indication that someone thinks there is a potential in the idea and is willing to invest in an application (Vinnova p 44). However, it should be mentioned that patent statistics is not a perfect measurement of research productivity based on the fact that not all inventions are patentable and not all inventions are patented. It is also worth noting that patented inventions differ in quality (Griliches 1990 p 1669).

2.3 Commercialisation of technology

As stated in the above chapters, innovations are the key to high and sustainable growth in today's modern economies. Investments in R&D, both by public and private actors, are certainly important for the creation of new technology. And for innovations to generate economic growth the process of commercialisation is of uttermost importance. As with the example of Sweden, which relatively spends the highest percentage of GDP on R&D in the EU but is still lagging behind in creation of new technology, there is reason to believe that the crucial part of commercialisation is not fully working.

A common understanding is that academic research is decisive for the development of high technology and it is therefore considered the engine of the industry of high technology. Although, academic research is just one part of the commercialisation of new technology. Investments needed to put a profitable innovation into industrial scale production and distribution are often many times bigger than the initial investments made in the research effort that is put in to create innovation (ISA 2003 p 101).

An economic report from Invest in Sweden Agency highlights the problem of Sweden's surplus of technology that it cannot manage commercially (ISA 2003 p 9). The lack of business and commercialisation competence is evident and must be handled in order for Sweden to retrieve high and sustainable growth in production (ibid). Therefore, there is a need for foreign investors and a mixture of domestic and foreign actors on the Swedish market (ibid). This claims for an attractive investment climate and the Swedish tax system is in the need of a transformation in order for Sweden to be competitive and attract both foreign and domestic competent labour force (ibid p 10). In the process of commercialisation of innovations it is important to have an open climate in that sense that both foreign capital and foreign competence is attracted to the country. A country's openness is crucial as an important component for facilitating commercialisations of innovations (den Butter et al 2008 p 201,204,209). Companies in an open country can also easier reach a bigger market and earn a larger profit. This is an area in which governments play a crucial role. Policies must also facilitate for SMEs (Small and Medium Enterprises) and new enterprises and the venture capital (VC) industry has to be complemented with foreign capital (ISA 2003 p 10). The ISA report specially highlights the importance of entrepreneurship and competent industrial venture capital to manage the commercialisation of the new technology in the country.

Commercialisation of technology always demands critical elements of economic knowledge (ISA 2003 p 35). The competence of entrepreneurs is needed to sort out the most profitable innovations from the total stock of innovations. Additionally, market incentives have an essential role in the commercialisation process where innovations are translated into commercial goods and services. The drivers behind this are often private firms interested in earning profits (Romer 1990 p 72). This also calls for venture capitalists with industrial knowledge, who are crucial in contributing with understanding of the entrepreneurs' projects and by offering industrial knowledge and somewhat long term financing (ibid). However, venture capitalists are not interested in a long term undertaking in the project and seek to exit with a good profit relatively soon. Therefore, broad exit markets and competent industrialists are needed in order to put winning projects further to production and industrial scale distribution. The point here is that innovations as an input is not sufficient to generate growth (ibid).

3 The Romer model with innovation

This chapter starts with an introduction to the implications of the original Romer model and is followed by our extended model where we include measurements of productivity and commercialisation.

3.1 The basic Romer model

In 1990 economist Paul M. Romer published the article “Endogenous technological change” presenting a model that gives an endogenous explanation to the source of technological progress (Romer 1990 p 99). The basic assumption is that technological change lies at the heart of economic growth and together with capital accumulation it explains much of the change in output per hour worked (ibid p 72). In Solow’s neoclassical growth model technology grows exogenously at a constant rate (Jones 2002 p 99). Whereas, in the Romer model researchers are driven by market incentives and seek to maximize the profit from their inventions and thus the technological change is endogenous (Romer 1990 p 72). The characteristics of technology is nonrivalry, meaning that ideas can be used by several individuals at the same time and as many times as desired at no additional cost (ibid p 72). The Romer model assumes the economy to exist of three sectors. The research sector, that with human capital and the existing stock of knowledge produces new ideas. The intermediate goods sector uses the designs that the research sector has produced and foregone output to produce goods for the final sector. And the final sector uses labour, human capital and the set of durables to generate the final output (Romer 1990 p 79).

The Romer production function:

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

(Equation 1)

In per capita terms output is described as:

$$y = k^{\alpha} A^{(1-\alpha)} \left(\frac{L_Y}{L} \right)^{(1-\alpha)}$$

(Equation 2)

As the production function above states output, Y, is produced by combining the production factors capital, K, and labour engaged in producing output, L_Y, using the stock of ideas (or technological level), A. This indicates that for a given stock of ideas, there are constant returns to scale in capital and labour. However, since technology is also an input to production there is increasing returns to scale due to the non rival nature of ideas (Jones 2002 p 98).

Capital is accumulated in accordance with the Solow models function for capital accumulation:

$$\dot{K} = sY - dK$$

(Equation 3)

Technology, A, is thought to accumulate as follows:

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

(Equation 4)

Where $\dot{A}$ illustrates the new ideas that are produced at any given point in time, which here is given by the number of persons working in the R&D sector, L_A, multiplied by the rate at which they discover new ideas $\bar{\delta}$. The change in the delta variable is in turn described as:

$$\bar{\delta} = \delta A^{\phi} L_A^{\lambda - 1}$$

(Equation 5)

In this equation δ and φ are thought of as constants. If $\varphi > 0$ the indication is that the productivity of L_A increases with the stock of ideas that are already existing and if $\varphi < 0$ this illustrates the fact that new ideas may be harder to discover over time (Jones 2002 p 99). When the parameter $\varphi=0$ the productivity of the researches is independent of the stock of ideas, A (Jones 2002 p 100). In addition to the above mentioned discussion, it is also possible that the rate at which new ideas are discovered depends on the number of researchers. This is mostly due to that the risk of duplication (of ideas) increases with the number of people employed in the R&D sector. Consequently, the function for accumulation of technology is modified by adding the parameter λ to the variable for researchers, L_A. The λ parameter is between 0 and 1. The function for technological change therefore looks as follows:

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

(Equation 6)

Along the balanced growth path, the so called steady state, the production factors capital, labour and technology grows at the same rate:

$$g_y = g_k = g_A$$

(Equation 7)

This means that if there is no growth in technology there is no growth in the economy as a whole.

3.2 The extended model

With the discussion on innovation and economic growth in chapter two as a point of departure, the Romer model is here extended to take notice of the importance of commercialisation of technology. In addition to that there is a modification of the parameter describing the productivity of the research sector (δ). This is conducted by adding two indexes into the model. These indexes will be tested empirically in the next chapter of this thesis. The production function and the function for capital accumulation in our extended model are the same as in the original Romer model (see Equations 1 and 2) and hence there is no need for further deliberation on that topic.

The algebraic details of the derivations of this chapter are found in Appendix A.

3.2.1 Technological change

Our purpose of making this extension of the model is to develop the expression for how new ideas are generated, i.e. the accumulation of technology. In contradiction to Romer's original model, which states that the creation of new technology is dependent on the number of persons working in the R&D sector and the productivity of that sector, we claim that it also depends on the commercialisation capacity of the economy, and that productivity can be explained further than just with a constant parameter. Accordingly, our extension of the model contains a more empirically rooted measurement of productivity in the research sector and an inclusion of a variable explaining commercialisation. Therefore, let us as a start assume that technology is accumulated as follows:

$$\dot{A} = \bar{\delta} L_A \bar{I}$$

(Equation 8)

This means that $\dot{A}$, the number of new ideas that are produced at a certain point of time, depends on the rate at which new ideas are discovered ($\bar{\delta}$), the number of people working in the R&D sector (L_A) and the rate at which ideas are commercialised ($\bar{I}$). To describe this further, the rate at which new ideas are discovered, i.e. the productivity rate equals:

$$\bar{\delta} = \delta^{\mu} A^{\phi/2} L_A^{\lambda-1}$$

(Equation 9)

The indication here is that changes in productivity are determined by the existing stock of ideas (A), based on the same assumptions as in Romer's model that prior innovations raise the productivity of the development of new ideas. It is also dependent on the number of individuals in the R&D sector (L_A). In addition to that, productivity (δ) is also a determinant for changes in the productivity rate. But in contradiction to Romer's model, δ is here a variable instead of a constant parameter. This variable will be represented by the index for productivity that we will construct. The δ index consists of a number of variables that affect the productivity in the research sector. With theory and intuition we have identified a number of indicators that do, and which will be added to the model and tested empirically in a regression. The productivity of the R&D sector will be explained by factors such as soft infrastructure, employment and educational indicators, openness, a measurement of output from universities and corruption. As understood here the δ index consists of a number of factors that can grow at different rates. Regardless of that, we believe the index to grow at a constant rate, even though the size of the constant is determined by the growth rates of the variables in the index.

Since we have developed an already existing parameter, δ, and now treat it as a variable we have to assume that our index does not explain the total productivity of the research sector as it was meant to do in the initial model. Consequently, we included a constant in the index. This constant is meant to capture the parts of the productivity that our variables cannot explain, i.e. the difference between our empirically estimated expression of δ and the δ that is added to the equation in the original model. Further discussion on the creation of the indexes is found in chapter five.

Finally we want to acknowledge the parameter that the δ index is given here (μ). This parameter is added with the purpose of slightly reducing the impact of our index. We do this because we want our index to affect the accumulation of technology in moderation. In accordance with estimations of parameters in other economic growth models we assume the value of the parameter to be between 0 and 1. Noticeable are also the parameters φ and λ, which are the already existing parameters in Romer's original model. The λ parameter represents the possible effect of duplication in the research sector and φ represents the impact prior technology has on the development of new technology as discussed in section 3.1 of this thesis. They are also assumed to be between 0 and 1. The parameters φ and λ will hereafter always have the same functions as described here.

We now continue to discuss the rate at which innovations are commercialised, which is determined by:

$$\bar{I} = I^{\gamma} A^{\phi/2}$$

(Equation 10)

The expression shows that changes in commercialisation are dependent on commercialisation (I) and the already existing stock of ideas (A). We believe that if a country has a high technological level they are in the so called technological front which is an indication that the country is more capable to absorb new technology and its spill-over effects. It may also be a sign of an already well-functioning capacity to commercialise new technology. The same principle as in the equation for changes in productivity are found here as commercialisation (I) is represented by an index. This index has the purpose of describing the capacity of commercialisation in the economy and its components are also identified through empirical testing. The variables included in the commercialisation index are entrepreneurship, different types of investments and interest rate. For more explicit definitions of the variables see chapter four.

Growth in this index is explained in the same way as growth in the productivity index, i.e. it depends on a number of variables that grow at different rates but the overall growth of the index is thought to be a constant whose size is dependent on the variables' different growth rates. The commercialisation index is also given a parameter (γ) based on the same arguments as for the δ index and with the same characteristics as μ.

With the above discussions in mind we can now see that the final expression for accumulation of technology is:

$$\dot{A} = \delta^{\mu} A^{\phi} L_A{}^{\lambda} I^{\gamma}$$

(Equation 11)

In the original model accumulation of technology looks the same except that it now also depends on commercialisation capacity and δ is now a variable instead of a constant. The indexes are added to the model to render analysis on the economy that is more in line with the reality. With the commercialisation index we want to emphasize the importance that commercialisation has for accumulation of technology. And with the new productivity variable we want to be able to give a better understanding of how productivity in the research sector can be measured.

The growth rate in technology is written as:

$$g_A = \delta^{\mu} L_A{}^{\lambda} I^{\gamma} A^{\phi-1}$$

(Equation 12)

This expression shows that the growth rate of technological change is dependent on the number of researchers working in the R&D sector (L_A), the existing stock of ideas (A), the productivity of the research sector (δ) and the capacity to commercialise new ideas (I). The new in this equation is that a variable for commercialisation is included.

3.2.2 Steady state

In order to solve the model it is crucial to identify the expression for output per capita in steady state. Steady state shows us how the economy grows when the variables in the model grow at a constant rate along a balanced growth path. The economy is hardly ever in its steady state position, but it is however important to identify this situation since it is useful when making predictions of how the economy will develop over time.

In order to identify the steady state we have to know what determines growth in GDP.

$$g_y = g_k = g_A$$

(Equation 13)

It is here shown that growth in GDP is determined by the growth rate in capital and technology as in the original Romer model (for proof se appendix A).
By taking the logs and derivatives of the g_A function we can find out that the determinants of the growth rate of technology in steady state are:

$$g_A = \frac{\mu g\delta + \lambda n + \gamma gI}{1-\phi}$$

(Equation 14)

This means that in equilibrium growth in technology depends the growth in the labour force, n, and with our extension of the model it also depends on the growth rate in δ and I. The growth rate is also dependent on the parameters of the $\dot{A}$ function, i.e. how large the stepping-on-toes effect, λ, is (the risk of duplication) and how large the standing-on-shoulders effects, φ, is (how much the already existing technology contributes to the creation of new technology). The parameters of the indexes also determine the growth rate of technology. In the original Romer model δ is assumed to be a constant which does not grow when in equilibrium. However, in our extended model we mean that δ is not a constant, but it may grow at a constant rate and the size of the constant is determined by a number of variables that all grow at different rates. However, when the economy grows along a balanced growth path, when all variables of the model grow at a constant rate, δ is also assumed to be in equilibrium and grow at a constant rate, g_δ. The index for commercialisation, I, also grows at a constant rate when in steady state, g_I.

The final expression for GDP per capita in steady state is found below.

$$y^* = \left(\frac{s}{(d+g_A+n)}\right)^{\frac{\alpha}{1-\alpha}} \left(\frac{L_Y}{L}\right) \frac{\delta^{\mu} L_A{}^{\lambda} I^{\gamma} A^{\phi}}{g_A}$$

(Equation 15)

The above expression concludes that the indication of the economy in steady state corresponds to the results of Romer's original model in that sense that the savings rate (s) affects output per worker positively since a higher savings rate leads to a larger stock of capital. Whereas depreciation of capital (d) affects output negatively since depreciation decreases the capital stock. Population growth (n) also has a negative influence since output is here expressed in per capita terms, which means investments must be higher in order for the GDP per capita to be constant. The population growth does have a positive effect on output in steady state by providing more persons that can work in either the producing part of the economy (L_Y) or as a part of the workforce in the R&D sector (L_A). Noticeable is that the technological growth rate (g_A) affects output in a negative way in two parts of the equation. On the other hand, growth in g_A is to be considered as positive since it raises the technological level (A) which is another determinant of the output level and as shown in the last part of the expression A raises GDP per capita in steady state.

The productivity index (δ) affects GDP per capita in steady state positively. This corresponds to our intuition that productivity is important for the development of new technology and that technology in turn increases output per worker. Commercialisation, which is represented by the index I has a positive influence on output as well. As argued before, commercialisation is crucial in bringing new technology to the market and into the GDP production. Consequently, greater commercialisation capacity can increase GDP per capita in steady state.

4 Econometric framework

In this chapter we will try to explain the econometric method that we have used. There is a discussion about the OLS regression, the test methods and corrections that we have made in order to be able to make a correct inference. We will also discuss our choice to use panel data and its implications. Finally we will present the data for the indexes and describe which variables that are included.

4.1 Multiple regression

A multiple regression is a regression with more than one explanatory variable that might affect the dependent variable (Gujarati 2006 p 208). Most regressions are multiple because there are only a few dependent variables that can be explained with only one variable (ibid). With a regression like this we want to find out how a one unit change in the explanatory variables (X) influences the dependent variable (Y) when the other explanatory variables are held constant (ibid p 211-212).

4.1.1 The OLS regression

In our work with constructing the indexes we have used a regression called OLS (Ordinary Least Squares). The OLS is a method easy to use and it is also well rooted in economic theory. The properties can be summarised in the Gauss-Markov theorem. Given the assumptions of the classic linear regression model the OLS-estimates will have the minimum variance when choosing between the linear estimators, that means that they are BLUE (Best linear unbiased estimators) (Gujarati 2006 p 174). Since we are using panel data there can be some problems to make a correct inference. We will in the following section try to declare what tests and corrections we have to make to get a proper model with a possibility to make a good inference.

In order to create a correct inference we have to make clear that there is not any heteroskedasticity in the data. The variance of the error term has to be constant. If the variance is not constant we have heteroscedastisity. If we have heteroscedactisity in our data and do not correct for it the estimates might not be the most efficient estimates (Gujarati 2006 p 212). To see if this is true there are several tests to make, such as White's test or the Goldfeld-Quandt-test. But because we have panel data we cannot perform any of them in Eviews. This might not be a problem since we used a "Coefficient covariance method" and we therefore dealt with that problem to that extent that it is possible.

We also have to control for autocorrelation in the data. If there is autocorrelation it means that there are correlations between "members of observations ordered in time" as in time-series data (Gujarati 2006 p 428). The error terms should be uncorrelated, but this is not always the case when using time-series data (Gujarati 2006 p 212). We use the Durbin-Watson (DW-statistic) method to detect if there was any autocorrelation. In our case if the DW-value is under 1.7 it is a sign of positive auto-correlation and if it is larger than 2 it is a sign of negative autocorrelation. It is possible to use a "Generalized least squares" – a transformation of an OLS to deal with autocorrelation and through that we have adjusted the standard errors. It is also possible to plot the residuals (the estimated error term) to visually see if there is any sign of autocorrelation.

It is common that a regression with time-series data has non-stationary variables. A variable is stationary if its mean value and variance is constant over time and the covariance between two different values has to depend on the time distance between the two values and not on the time that the variable actually were observed (Westerlund 2005 p 202; Gujarati 2006 p 496). If a variable is non-stationary it has a one unit root. One unit root is the sum of all the earlier error terms. That sum is called stochastic trend because this will affect the variable so it almost looks like a linear trend, that either increase of decrease with time (Westerlund 2005 p 204). But the stochastic trend is random and seems to increase or decrease with time. One unit root and stochastic trend are basically the same thing. If the variable is stationary it would not be dependent on the time (ibid p 205). If we include some non-stationary variables the inference would be incorrect, and there is a risk of spurious regression (which is common in macro economics) (ibid p 201 & 205). That is why we performed a one unit root test in Eviews for each of the variables to see if whether or not our variables are stationary.

We also wanted to control if the regression had any collinearity. A proper inference does not allow perfect collinearity between the different independent variables (X_2, $X_3 \ldots X_n$). This assumption is known as the no-collinearity or multicollinearity assumption (Gujarati 2006 p 212-213). If this is not true, you could exchange one of the variables with one that is exactly correlated with another one, the explanatory variables may be dependent on each other in a systematic way (Westerlund 2005 p 159; Gujarati 2006 p 213). If we have multicollinearity among some of the explanatory variables we can still make an OLS regression but we cannot have any unique estimates of all the parameters, meaning that we cannot separate the effect from the individual regression parameters (Westerlund 2005 p 159; Gujarati 2006 p 366). And because we cannot obtain unique values we cannot draw a correct statistical inference. The estimates' variance and covariance will then be larger than they should which lead to larger standard error and the t-statistic will be small (Westerlund 2005 p 160; Gujarati 2006 p 366). Because of that the variable will look more significant than it really is (Westerlund 2005 p 160). You can see whether or not your data has traces of collinearity if you have a high R^2 and few significant t-ratios or by using a correlation matrix over the explanatory variables (Gujarati 2006 p 372).

In order to make a correct inference the error terms should be normally distributed with a mean zero and variance σ^2 (Gujarati 2006 p 213). If our sample is not that large the error terms have to be normally distributed. Otherwise it is not possible to construct a confidence interval and to test hypotheses of the models' parameters (Westerlund 2005 p 134). If this is not the case then it is not possible to make a correct inference. Here we can use the Jarque-Bera test to control for the skewness (if the distribution is symmetric around the mean value) and kurtosis (the size of the tails) of the residuals to see if they seem to be normally distributed. If it would be a normal distribution the residuals would be perfectly symmetrical around its mean and also have a kurtosis of three, if this is true the JB value would be near zero (ibid p 134).

4.2 Panel data

In this study we used panel data and by doing this we could make one regression for all the data with both cross-section and time-series data (Brooks 2008 p 488). With panel data it is possible to study a broader spectrum of issues and also handle more complex problems than with either only time series-data or only cross-sectional data (ibid). When using panel data it is also possible to increase the number of degrees of freedom and thus the power of the test by using information on the dynamic behaviour of large number entities at the same time (ibid). A positive thing with panel data is that it allows us to study dynamic relationship which we cannot do using single cross-section data (Wooldridge 2002 p 169; Kennedy 2008 p 282). In addition to that panel data also allow us to control for unobserved cross-section heterogeneity (ibid).

With panel data the regression looks as follows were y_{it} is the dependent variable, α is the intercept, β is the parameter to be estimated on the explanatory variables and x_{it} is an estimation of observation on the explanatory variable and u_{it} is the error term (Brooks 2008 p 487-488).

$$y_{it} = \alpha + \beta x_{it} + u_{it}$$

Panel data can be either balanced or unbalanced. With a balanced panel we would have the same number of times-series observations for each cross-sectional unit (Brooks 2008 p 490). An unbalanced panel would have some cross-sectional elements but with fewer observations or observations at different times, the number of observations can be different for different countries (ibid). Our data is unbalanced data, because we do not have observations for all the variables, and every country in every year. The technique is similar for both methods when we are using the program of Eveiws.

4.2.1 Fixed or random effects

Working with panel data as we are, it is essential to make sure that there are no other effects than those you want to capture that affects the outcome of the regression. For that purpose it is possible to use the method called fixed effects. The fixed effects method enables us to correct for external effects that could affect the outcome of the regression and that are specific for a certain time or a certain country. With a fixed effects model it is possible to let the intercept vary cross-sectionally but not over time (Brooks 2008 p 490). This way it would correct the coefficient values for other things that could happen in the economy and that could affect the outcome of the dependent variable. Accordingly, the fixed effects approach means removing cross-section or time specific means from the dependent variable and the exogenous regressors. Thereafter the specified regression is performed on the demean within the transformed variables (Eviews Users Guide II).

The random effects model is appropriate when you assume that the unobserved effects are random, i.e. they are effects of random variables or outcomes of random variables. One assumption that is required here is that the unobserved effects are uncorrelated with all the explanatory variables (Brooks 2008 p 498). This model is more appropriate to use when you have a large sample, which is not the case in our analysis. Therefore we can reject the thought of using a random effects model.

Eviews provides us with tests for the use of fixed or random effects, called the "Redundant fixed effects likelihood-ratio" for fixed effects and the "Hausman test" for random effects.

4.3 Data and variables

We have collected our data from Eurostat, World development Indicators and OECD. In our index for productivity we have 16 countries and13 time periods. The 16 countries are the EU-15 plus Norway. We have selected these countries because they all are similar concerning R&D level in the country, and they also have similar GDP and educational level, all things that have importance in the Romer model. We included Norway since it is a European country very similar to the countries in EU 15, and it also increased our number of observations which was an important aspect. The 13 times periods were chosen given the supply of data. By choosing the period between 1995 and 2007 we could collect data for almost all the variables during that time period. Unfortunately, we could not find data for more than 8 years when we chose the variables for the commercialisation index (2000-2007).

The variables that we have chosen to include in our indexes have been selected with earlier studies in mind and also theories concerning innovation. But since there has been some problem in finding usable data for all the years that we wanted to study we had to limit the years that we collected data from. It was especially hard with the index for commercialisation. The most evident problem is that variables that would be interesting to include in the indexes are hard to quantify and also that the research in this area is relatively new. Therefore, the reader should bear in mind that the variables that are included in the index were chosen from a limited range of variables.

4.3.1 Index for productivity

Patent - The dependent variable

The dependent variable patent is the number of patent applications to the EPO (European Patent Office) per million inhabitants. This is our measurement for the productivity in the research sector. We have chosen this variable to be the dependent because it is a common measurement when a researcher wants to study and measure innovation across countries (Smith 2005 p 148; Kim 2007 p 139; Ulku 2007 p 294). It is usually number of patents, number of scientific journals or R&D expenditure that is being used as a dependent variable when studying innovation capacity. We think patent is the most appropriate choice of these three variables, since patent is by definition a receipt of an innovation and also a clearer measurement of research output. We have to acknowledge the fact that some innovations never can be patented and in this aspect number of scientific journals could have captured more innovations than patent applications do. To use patent as the dependent variable is despite the discussion above the right choice because patent is closer connected to improved production possibilities in the economy (Kim 2007 p 140; Vinnova 2003 p 42). Because of the costs and the work of a patent application we have reason to believe that no applications will be done if there is no economic profit in sight (Smith 2005 p 159).

Using the variable patent it is also possible to get better data for longer time periods, since that is something that has been measured across a vide range of countries for a long time. Worth noting is that this variable only covers patent applications that have been sent to the EPO.

Internet

We have also included the number of internet users in our regression. This variable serves as a measurement of a country's soft infrastructure. One reason for including the internet variable is that innovations in large part rely on technology infrastructure (Smith 2005 p 151). Access to internet also decreases transaction costs through lower costs of search and information (den Butter et al 2008 p 205). Not only does this lead to lower transaction costs which can increase research productivity in that sense that less resources must be spent on information search but it can also be important in that sense that it leads to time saving and increased effectiveness. It is hard for people to come up with new ideas if they lack infrastructure that support their R&D activities (Kim 2007 p 148-149). Internet also affects the possibilities to communicate and distribute research results (Pavitt 2005 p 98). A well extended and high quality infrastructure services is also important in attracting foreign investors and skilled researchers (OECD 2008 p 28-30). These are all factors that are vital for the productivity of research.

Journal

The variable journal consists of a number of scientific and technical journal articles. We wanted to include this variable since it is a good measurement of how productive a university is, given that it is important that a university has a lot of researchers publishing their findings. Journal is also a traditional measurement of the productivity of research and that is why we included that variable (Vinnova 2003 p 42). Scientific publications (bibliometrics), publications in trade and technical journals could be a good complement to patent when measuring science and technology activities (OECD 2005 p 22). Bibliometric data is an indicator that has been used measuring innovation capacity (Smith 2005 p 135). Literature and journals can work as sources for transfers of knowledge and technology, which could have a positive effect on the productivity (OECD 2005 p 81).

Trade

The variable trade is measured as a percentage of GDP. Trade has been proven to affect the patent capacity in earlier studies (Kim 2007 p 155). It seems as if countries that have a lot of trade also have a higher willingness to apply for patents (ibid p 154). It also seems as if the countries that have a higher import of manufacturing goods also have a larger amount of researchers (Ulku 2007 p 297). For us this is a measurement of the degree of openness that the country has. The higher degree of openness (as trade can be an implication of) could affect the productivity of patent in several ways, through spill-over effects from other countries, researchers from foreign countries might come to work in the country, increase the GDP as whole (Ulku 2007 p 299 & 303). Good international cooperation is also something that could affect the productivity in a positive way, through lowering some of the transaction costs that could arise when trading goods (den Butter et al 2008 p 205).

Knowledge intensive service sectors (KISS)

This variable covers employment in knowledge intensive service sectors as a share of total employment. To work in a business sector where the development is fast requires skilled labour able to keep up with the changes. In a knowledge-based economy the information technology largely consist of infrastructure, it has a role in the economy to facilitate the productivity investments (Tassey 2004 p 153). If a country has a structure of the production where a large amount of the population is employed in knowledge intensive sectors it could be an indication of a country's industry production. The knowledge-based services are the largest source of economic growth for the US economy Tassey says (Tassey 2004 p 153). Knowledge-based companies have a significantly higher share of employment with a university degree then other companies (Lööf 2008 p 30). Knowledge –based companies or companies working with high technological development have higher costs for the innovation process than other companies do (ibid). If you are interested in having a high productivity in innovations we think it has shown important to have a large share of the population employed in this kind of knowledge-intensive sector.

Employment of educated people (EMP)

We have also chosen to include a variable that contains data over the employment rate by the highest level of education attained as a percentage of the population aged 25-64 years. To have a well educated population is important in many ways. First, this makes it easier to recruit competent researchers but it is also important to achieve spill over effects (Kim 2007 p 148; Ulku 2007). We are interested in identifying a country's capacity to absorb the human capital by offering well-educated people work. But instead of just looking at the number of people with a higher education we thought a measurement that showed if they also had a job that required the higher education was more interesting. That a population with higher education is good for creating innovations might not be a controversial statement (Edquist 2005 p 192).

Corruption (CPI)

We also included a variable for the level of corruption in a country. There is evidence in earlier studies that the legal structure such as intellectual property protection has an effect of the knowledge production process (Kim 2007 p 154). If the country can control corruption that could lead to an increased level of trust, and that will also be associated with rising levels of innovation and entrepreneurship. And the other way around, if there is an absence of trust, monitoring and other transactions cost should limit trade and thus, hinder productivity and investment in innovation (Anokhin et al 2009 p 465). Corruption can limit the revenues and lower the potential value of the returns of the opportunity if it affects the country's infrastructure, and through that the transactions costs. But if there is no corruption it is realistic to assume that the entrepreneur or innovator will get a larger gain and thus motivate higher levels of entrepreneurial and innovative activities (Anokhin et al 2009 p 467).

4.3.2 Index for commercialisation

Newly started businesses - The dependent variable

For dependent variable in the index for commercialisation we have chosen newly started businesses. According to a report from the Swedish authority Vinnova newly started businesses is a traditional variable when talking about innovations and commercialisation of university results (Vinnova 2003 p 43-44). It is important not only focusing on the number of newly started businesses but also at the innovation process as whole. We are aware that this measurement only captures the registration of the businesses and not the turnover or another measurement of how much profit the new innovation of innovative products are generating (ibid). But since it is (once again) difficult to find data we find this the best suiting variable to use when studying how the commercialisation of the innovation proceeds.

Interest rate (INT)

In this index we also included a variable for interest rate, the long interest rate. We think that this might affect the possibility for a company to be granted a loan to expand their businesses. To include a variable that reflect the economic condition of a country at the time when a patent application is done could be an interesting way to study the effect on the productivity (Kim 2007 p 150). The interest rate that the entrepreneur is facing might affect the investment rate since, with a high interest rate it is harder to get finance capital for your project. We wanted to find a structural measurement of the economic status to use when studying how this affects the commercialisation of innovations.

Foreign direct investment (FDI)

We have also included a variable for foreign direct investment in this index. If a country can increase the FDI coming in to the country it would help newly started businesses to commercialise their inventions and also make the procedure to the international market easier, both by giving economic financing and knowledge from a different perspective and other markets. Our understanding is that FDI works in a similar way as trade in that that it may carry spill-over effects when coming in to a country (Verspagen 2005 p 508). As we see it, on of the differences between FDI and trade is that trade is a more general measurement of openness whereas FDI is more a measurement of competitiveness. The is also a difference between FDI and VC in that sense that venture capitalists have to face a higher risk than foreign investors might do.

Entrepreneurship (ENTR)

Another variable that we have chosen for the index of commercialisation is entrepreneurship. This variable is constructed from survey data. Respondents have in a telephone interview answered the question whether they prefer to employed or self-employed (Eurobarometer 2007 p 6). Entrepreneurship has many economic benefits like job creation, competitiveness and also growth, and because of that we chose to include this measurement in the index (ibid p 4). EU also finds it is important to “encourage entrepreneurial initiatives and unlock the growth potential of its companies and citizens” (ibid). Entrepreneurial environments have been the key to growth in the knowledge-based economy in the US a researcher says when comparing Sweden and the US (Vinnova 2003 p 61). Entrepreneurs are crucial in the process of finding a successful and profitable innovation and put them on the market (ISA 2003 p 33).

Venture capita (VC)

The variable for venture capital was composed by merging data for venture capital in early stage investments and expansion and replacement investments, both measured as percentage of GDP and thus creating one variable for venture capital. We have chosen this variable since it is proven in earlier research reports that this has a clear effect on innovation capacity (Lam 2005 p135; Lazonick 2005 p 46; O’Sullivan 2005 p 251-253). It is reasonable to believe that if there is a lot of venture capital available it will increase the commercialisation capacity since it makes it possible to support entrepreneurial projects with high risks (ISA 2003 p 33). Some initial capital to get the new product or service to the market, and also an individual with competence in the area that he or she could contribute to the businesses with is positive (ibid).

As stated in chapter 2.3 the importance of competent industrialists is also emphasized as a key for successful commercialisation. Unfortunately we have not been able to find an accurate indicator, and thus data, for industrialists and hence not been able to include such variable in the regression.

5 Empirical findings

In this chapter we present our results from the regressions that we will use when constructing our two indexes. Depending on the value of the β-coefficient the different variables will have a responding weight in the index. An extended discussion of the results from the regression outputs will be examined in chapter 6.

5.1 Methodological considerations

Given the use of panel data and the nature of our data we have made performed a number of tests and made some corrections, all in effort to fulfil the OLS assumptions and thus to be able to estimate a correct model with the best estimates closest to the true model. The tables from our tests are found in Appendix C.

As showed in chapter four we used the "White cross-section" as a coefficient covariance method which helped us deal with heteroscdasticity. We used the same method for both indexes.

To find out if we had any autocorrelation (which we expected since it is common using time-series data and also because we had a low DW value and high R^2 value) we plotted the residuals in the model. Thereby we discovered that we had positive autocorrelation in the data. Therefore, we applied a GLS-method, a transformation of an OLS that deals with autocorrelation by adjusting the standard errors, called "cross-section weights" in our data program.

We also conducted a panel unit root test for all the variables to see if we had any non-stationary variables and it showed that and that the variable FDI was non-stationary. We differentiated the variable to get rid of the non-stationarity (first level difference in Eviwes) and this will appear as d(*variable*). Thereafter we made the panel unit root test again and now it showed no sign of non-stationarity. From that we draw the conclusion that we succeeded in our correction for non-stationary among our variables.

Thereafter we constructed a correlation matrix to see if any of the explanatory variables were highly correlated with another explanatory variables, if the data hade any sign of multicollinearity. The matrix shows that none of the variables in the two indexes are highly correlated with one another (see Appendix C). If two explanatory variables have a correlation over 0.8 one should consider excluding one of the variables (Westerlund 2005 p 160).

To see if our residuals were normally distributed made a histogram over the residuals. For the first index (for productivity) our Jarque-Bera value is in the acceptance area (2.18) and the skewness (0.26) and kurtosis (2.7). For the second index (for commercialisation) the Jarque-Bera value is (134.8) and the skewness (1.77) and kurtosis (7.79). Studying the histogram for the second index we could see that there were some outliers, and that of course affects our JB-value (Brooks 2008 p 164-166). We did not however want to exclude this observation since we only have 91 observations and visually, the distribution looks good. Consequently, we leave the observations as they are.

Finally, we tested if our regressions should have fixed effects or not. Both tests showed that fixed effects were not applicable to our models.

5.2 Regression output for productivity

We use the following OLS regression as a way to find the variables and their weight in our index.

$$PATENT_{it} = \alpha + \beta_1 CPI_{1t} + \beta_2 EMP_{2t} + \beta_3 INTERNET_{3t} +$$
$$\beta_4 JOURNAL_{4t} + \beta_5 KISS_{5t} + \beta_6 TRADE_{6t} + \varepsilon_{it}$$

The table below illustrates the output from our regression with patent as the dependent variable.

Dependent Variable: PATENT
Method: Panel EGLS (Cross-section weights)
Total panel (unbalanced) observations: 147
White cross-section standard errors & covariance (d.f. corrected)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	80.07469	58.08803	1.378506	0.1702
CPI	16.92019	2.070082	8.173681	0.0000
EMP	-3.124016	0.740785	-4.217170	0.0000
JOURNAL	0.001132	0.000153	7.376054	0.0000
KISS	3.258008	0.406054	8.023572	0.0000
TRADE	0.253081	0.038566	6.562296	0.0000
INTERNET	0.610470	0.152292	4.008556	0.0001
Weighted Statistics				
R-squared	0.902805	Mean dependent var		186.9124
Adjusted R-squared	0.898639	S.D. dependent var		185.4919
S.E. of regression	51.09602	Sum squared resid		365512.5
F-statistic	216.7331	Durbin-Watson stat		0.342506
Prob(F-statistic)	0.000000			
Unweighted Statistics				
R-squared	0.550750	Mean dependent var		123.9621
Sum squared resid	435242.7	Durbin-Watson stat		0.114419

We have decided to accept variables at a 1 % significance level. Therefore we can see that all variables included in the regression are significant and should be included in the index. The adjusted R^2 is now 0.90 which is a high number, but since we have conducted all of the test that are necessary to make a correct inference and we also made corrections for the problems we discovered we can now assume that this number is relatively reliable. Even after our corrections for autocorrelation and stationary our DW-value is still beneath the acceptance level, but since we made the correction and the DW value is rising we do not find this a problem any more.

From the table above we can see that all variables have positive coefficient values, except Employment (*Emp*). This negative coefficient does not go in hand with what we had predicted. It seems unrealistic that a high employment level for well-educated individuals should have a negative impact on productivity in the research sector. This result may depend on our data set. Since we have another variable (*KISS*) that in part is similar to employment in that sense that it also puts focus on employment and higher education we chose to exclude the employment variable (*Emp*) from the index.

All the coefficient values are comparably low, except for the corruption variable (*CPI*) which has a value of 16.

Below we have our index which is constructed by using the coefficient values (β) for respective variable. We have also included a constant term, η, with the purpose to capture the part of the index that we cannot explain. This is particularly important since we have taken an already existing constant from the Romer model which already has a description and our variables cannot explain the total productivity of the research sector. We are fully aware that our variables cannot cover the broadness that the constant had in the initial model.

$$\delta = 16{,}9CPI + 0{,}0011JOURNAL + 3{,}26KISS + 0{,}25TRADE + 0{,}61INTERNET + \eta$$

5.3 Regression output for commercialisation

We use the following OLS regression as a basis to find the variables and their weight in our index.

$$BUSINESS_{it} = \alpha + \beta_1 d(FDI)_{1t} + \beta_2 VC_{2t} + \beta_3 ENTR_{3t} + \beta_4 INT_{4t} + \beta_5 GDP_{5t} + \varepsilon_{it}$$

The table below illustrates the output from our regression with new businesses as the dependent variable.

Dependent Variable: BUSINESS
Total panel (unbalanced) observations: 91
White cross-section standard errors & covariance (d.f. corrected)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-17685.02	8383.552	-2.109490	0.0378
ENTR	2284.089	117.4041	19.45493	0.0000
VC	405593.4	37955.20	10.68611	0.0000
D(FDI)	80.63401	22.18596	3.634462	0.0005
INT	-13187.44	2313.796	-5.699480	0.0000
GDP	-8307.220	1086.304	-7.647234	0.0000

Weighted Statistics

R-squared	0.612971	Mean dependent var	93476.37
Adjusted R-squared	0.590204	S.D. dependent var	90037.20
S.E. of regression	67115.69	Sum squared resid	3.83E+11
F-statistic	26.92431	Durbin-Watson stat	0.553090

Prob(F-statistic)	0.000000		
	Unweighted Statistics		
R-squared	0.342873	Mean dependent var	70669.03
Sum squared resid	4.97E+11	Durbin-Watson stat	0.337700

This output shows that all our included variables are significant on a 1 % level. The adjusted R^2 value is 0.59, which is acceptable. As in the previous regression output the DW value is low, but the same discussion as before is applicable here too.

We have included *GDP* as an explanatory variable to help us find out if there is a close connection to the macroeconomic fluctuations of the included countries. Before this was done the R^2 value was considerably lower. It is not unexpected that the R^2 value rises when *GDP* is included since the relation between *GDP* and new businesses is naturally strong. While constructing the index we exclude *GDP* since that variable should not be a part of the explanatory factors for commercialisation.

All the explanatory variables except Interest rate have a positive coefficient which is in line with our intuition. However, all coefficient values except *FDI* has a very high number, which can be more deeply scrutinized, but that discussion will follow in the next chapter.

The index for commercialisation is constructed as the previous index.

$$I = 2284 Entr + 40559 VC + 80 d(FDI) + (-13187) INT$$

6 Analysis and final words

In this chapter we will discuss our extension of the Romer model and how it can contribute to the scientific discussion of economic growth and innovations. We will also discuss the method and results from our regression. The analysis will result in a final discussion, with conclusions from our study. We will also give some thoughts on further research in this area.

6.1 Analysis

6.1.1 The expanded theoretical model

The choice of the Romer model as a theoretical basis for our analysis in this thesis felt natural and most in line with the discussion on innovation and economic growth in chapter two. The Romer model emphasizes technology as the engine of growth and that particular link was what we intended to study empirically. We expanded the model with a new and more empirically rooted measurement of productivity in the research sector and also added an index for commercialisation.

In general, we claim that the more explicit and empirically rooted all elements of the economic growth models are the more useful the models will be. If the variables of the models can be measured with empirical data the less abstract and more interesting they would be.

A deeper study of the productivity is, in our meaning, both interesting and important. Productivity is in itself hard to define and thus complicated to measure. There is no self evident variable that can estimate the productivity of the R&D sector. In earlier studies expenditure on R&D has been used as such variable. However, both intuitively and empirically that variable is not always a sufficient measurement of productivity. As with the case of Sweden, there are countries that spend a lot of resources on R&D that still do not seem to produce more research output than countries that spend less. There may be structural problems that hinder that money spent on R&D generates enough research output. With that in mind we found it important to further study the productivity and to seek a more empirically rooted measurement of it. The initial parameter for productivity in the Romer model, δ, felt rather abstract. It felt natural to replace δ with our index and not to include yet another variable into the model. There is no point in itself to add more variables. Our contribution in this case is that we have identified an empirical tool to estimate the variable that Romer already has added to the model.

After having recognized an empirical way of measuring productivity in the research sector we realised that it would be interesting to add a variable that would represent commercialisation of technology. Following the discussion in chapter two, commercialisation is significant for attaining the most profit from new technology, both from an economic and a welfare perspective. A definition and measurement of commercialisation is unsurprisingly not done without complication. There is a clear lack of quantifiable data in this field of study. A significant part of variables that can explain commercialisation are so called soft indicators, which are hard to quantify. The interest of commercialisation of innovations and research in this area is relatively new compared to other fields of economics which of course can explain the poor supply of data. What may seem paradoxical is that this lack of research in this area is what raised our interest in deeper studies of commercialisation of innovations.

Nonetheless we find it of great importance and interest to dig in to this problem in our thesis. The index for commercialisation added to the Romer model here may not be as comprehensive as one could wish. It is however an attempt to empirically measure commercialisation of innovations. The lack of data has been evident, but we have constructed an index that can account for a country's commercialisation capacity. The adjusted R^2 value of the regression is however relatively high (59 percent), but this may be due to the inclusion of the control variable GDP growth. It may be the case that some of the variables in the regression have an effect on the dependent variable a couple of years after. This can be solved by lagging the variables. We chose not to lag any of the variables mostly due to the difficulty of estimating how many years the variables should be lagged. It is however plausible to draw the conclusion that for example a variable as FDI has an effect on newly started businesses a couple of years later.

How does our commercialisation index affect the model then? We argue that the placement of the index in the function for accumulation of technology, ($\dot{A}$) is logic. It could be argued that commercialisation has a connection to both research productivity and the development of new technology. It can affect productivity in that sense that a successful commercialisation may be an incentive for researchers to finalise their research and maybe earn a profit from a potential patent. In this way commercialisation capacity also affects the development of new technology through research productivity.

As follows from chapter three we can see that these two indexes also affects the economy in the long run in a positive way, in steady state.

The growth rate of the indexes show that an increase in the indexes affect the growth rate in technology and, hence growth in the economy as whole. Commercialisation of an idea generates more money which in turn can be spent on creating new ideas. It can also contribute to more effective production possibilities and create incentives to invest in more research to discover new ideas that can generate more money, an example of a market incentive.

Some of the variables in the indexes may of course affect other parts of the model, for example *Trade* and *VC* may affect the way that capital is accumulated. But in our meaning there is no point in explicitly showing these variables' function if they have the same purpose as capital in the model.

We are fully aware that the extension of the Romer model that we have done is not that intricate but it is a way to connect our regressions with empirical data to an adequate model for economic growth.

6.1.2 Econometric and empirical analysis

The choice to use an OLS model felt natural and the most fitting for our purpose. After the corrections we have made we now think it is possible to make a proper inference of our model and we can draw conclusions from our empirical findings.

Since a part of our purpose was to give an empirical understanding of variables that can affect the productivity and the commercialisation capacity of countries, we found it natural to use panel data in our regression. The virtue of panel data is that it includes both a time series and a cross section perspective, which feels necessary studying these types of problems. However, using panel data have caused some problems in the process of our econometric work. As we have mentioned before our statistical data program, Eviews, has limited our possibility to conduct tests, for example tests for heteroscedasticity. Even so, we have been able to go through with our purpose. Since panel data contains a time perspective it is crucial to be able to exclude the effects on the data which are just time effects. For example conjuncture fluctuations and other macro economic incidents that can affect the explanatory variables. In that case it is hard to isolate the relationship between the dependent and the explanatory variables that exists despite the economic fluctuations. One way of solving this problem is to use fixed effects in the regression model, which was our intention. However, the tests we made in Eviews showed the opposite, it was not appropriate for us to use fixed effects. In the index for commercialisation we instead used another method to control for economic fluctuations, since we assumed that the dependent variable in this model (new businesses) may be highly correlated with the economic status of the countries. Therefore we included a variable for GDP growth. By doing this we can better see the effects that the other variables have on new businesses. This showed an increase in the degree of explanation, which was not unexpected. But even without the GDP variable the explanatory variables were significant.

The most evident problem we had to encounter in the empirical analysis was the lack of appropriate data. First of all the time aspect has been a problem. Most of our variables have only been available in a short time period which decreases the number of observations. At times data have also been missing out for some countries at some years. It seems to us as if research in the field of innovation is a relatively new phenomenon which shows in the lack of appropriate data for longer time periods. With a point of departure in the theory of the Romer model we had to choose data for developed countries. And since there is a will in the European Union to invest in and promote innovations we found it suitable to base analysis on data over the EU15 countries and Norway. The lacks of data lead to a relatively low number of observations in our regression, 147 for productivity and 91 for commercialisation. However, we still consider the number of observations as sufficient for drawing conclusions.

In addition to that the data problem has also affected our possibility to find adequate variables to include in our regression, especially in the index for commercialisation. One part of the problem is that some factors that affect the commercialization capacity are hard do define and therefore also hard to measure.

In the index for productivity we used *patent* as the dependent variable which is in line with other researchers' understanding when studying the productivity of innovation. We wanted to highlight the fact that several countries with a high R&D expenditure do not have as high output in the research sector, as we mentioned before Sweden can be an example of such a country. And we mean that patent is an adequate measurement for the productivity and its relation to economic growth, since it is plausible to believe that there are economic incentives behind a patent application.

The variable for *corruption* (CPI) shows a clear relation to patent and highly affects the number of patents. The positive relation between a high CPI value and high number of patents was expected and indicates that the absence of corruption is important for the productivity in the research sector. It is expected since in a highly corrupted country people would not find it worth to apply for patents or even doing research since you do not have a possibility to protect and profit from your innovations. Also, high corruption may cause problems with funding aimed for research ending up in the wrong hands. You could also imagine that corruption could affect some of the other variables in the index, for example Trade and Investments. A country with corruption will face problems with lack of trust, which can result in restrictive investors and being isolated from trading on the world market.

The *Journal* variable is included since we think that this gives an indication of the productivity and effectiveness of the universities (and other comparable research institutes). It is possible to assume that the more journal publications the more patents are applied for. Journal is a good measurement of productivity since an article will not be published in a renowned journal if it does not contribute with new facts or information. Our results show that number of journals has a positive connection to patents.

The variable *Kiss* (employment in knowledge intensive service sectors) is included as an indicator of the structure of the labour market in the countries. We mean that it is important to know the spread in the labour market. If many people are employed in this kind of sector this is an indication of a knowledge intensive economy. The Kiss variable shows a positive relation to patent.

Trade is a variable which we mean represent a measurement of a country's openness against the world. An open country can easier be a part of knowledge transfer and the distribution of research results and innovations. For a small country this is especially important. An open country is more willing to produce goods and services that can be exported. A structure of openness makes it easier for countries to absorb and utilize the technology that is being distribution. It also contributes to cumulative research. Trade also shows a positive relation but slightly low effect on patent.

We also wanted to include a variable for soft infrastructure and we here use *Internet* (the number of internet users per 100 people). This indicator may not give a total measurement of the soft infrastructure. But we however think that it can provide an indication of the how developed the soft infrastructure is in the countries. It is important to have a well functioning soft infrastructure to be able distribute and use innovations. It is worth noting that this measurement has a roof, if the internet users reach 100% it cannot increase more. In the case that all countries should reach this level this variable would automatically be useless. The internet variable is positively correlated with patent, but with a slightly low coefficient value.

As seen in the previous chapter the variable *Employment* (Emp) is included in the regression but has a negative sign and therefore we excluded this variable.

The purpose with our index of commercialisation was to give an empirical picture over the factors that could affect a country's possibility to commercialise their research. We did not think the productivity measure was enough when describing innovations' contribution to economic growth. Mostly due to the fact that researchers may be granted patents for innovations that do not lead to any products or services that will generate in a profit and not be used in the production of GDP. In the index for commercialisation we used new *businesses* as the dependent variable. This was not an obvious choice since the research in this area is more limited than the one for productivity. It is also hard finding a measurement since there is not a clear definition of commercialisation as measurement and nor how it should be measured quantitatively. However new businesses is a measurement that has been used before and it was also possible to get data for this variable. We do believe it gives a good sign of the commercialising possibility since newly started business show that an entrepreneur believes that she or he could make a profit on the innovation, otherwise they would not have started the business.

The variable *entrepreneurship* (Entr) is positively correlated with new businesses. This measurement was included since we believe there must be some entrepreneurial people in the picture when starting up new businesses. This is also something that earlier research has stated before. Entrepreneurs are needed to find the profitable innovations and make them commercial.

The *venture capital* variable also has a positive correlation with new businesses. Venture capital is different from other investments because it is aimed at high risk projects. A project that normally would not get funding via a loan from a bank or other investors may get funding from a venture capitalist. A country that has many venture capitalists has a better precondition to commercialise innovations, since they are willing to take a risks to invest in insecure projects which many innovations are. Sometimes the venture capitalists also can function as business angels and not just provide funding but also knowledge and contacts in the industrial area and market in which the innovation will be introduced.

FDI also has a positive relation with new businesses. FDI affects new businesses in that that it both can provide funding but also knowledge and contacts outside the country. The presence of FDI in a country can also be a sign of openness and foreign ownership in the receiving country. It has shown to be important with foreign ownership since it can bring commercialization competence into the businesses and thus the country. Openness is important in both the productivity process and the commercialization process. But it is still more reasonable to include FDI in this index since it has a stronger connection to commercialisation.

The variable for *interest rate* (Int) has a negative correlation with new businesses. This is also in line with our intuition. If the interest rate is high there will be fewer enterprises that start up since it leads to a higher financial risk.

As we have said before *GDP* is only included to eliminate economic fluctuations and will therefore not be included in the index. As the reader can see the coefficient values are extremely high especially when compared with the previous index. It is also so as we said before when including *GDP* the adjusted R^2 value increases. This could indicate that the robustness is quite low. However, this index should more be considered as a hint of the relationship rather than a true explanation. To find relevant variables for a longer time period was very hard, and this of course affects the result. If it was possible to find data, we would want to include a variable for cooperation between universities and the business society, the structure of administrative regulations and costs when starting up new businesses, and maybe a variable for tax levels. In addition to that, a measurement for industrialists would be interesting to include. If we would have more observations this might increase the robustness of the model. Finding more variables has been very hard and by this we have realised that this area of research is quite unexplored. Although, we find that our index could be useful even though we have few variables and the high coefficient values.

6.2 Final words

Our purpose with this thesis was to give an empirical picture of innovation and also to describe its connection to economic growth. We do not claim to have showed the whole picture of the connection, but hopefully we have contributed in that sense that we now have a variable that can be measured and also created a new variable that will contribute in explaining the connection.

Even though our index, and then we especially think about the one for commercialisation does not have that high significance we still think it highlights an important result. It gives a finger point at things that could be important for the commercialisation process, and it would of course be profitable to collect a larger amount of data and also maybe work with some time lags to fit the data in regression better.

Our choice of data could of course be something that affects the result. It would have been interesting to include or compare other developed countries than just from the EU. There might be some structural or cultural settings within the EU that affects the result and that could have been explored when doing a comparison.

During our work we have discovered many things that would be interesting to study further. First it would be of great importance if data for more variables could be collected. Of course we are fully aware of the problems when measuring this kind of data but some things like the procedures for starting up a businesses or how strict the government regulation for newly started businesses are things that might be possible to measure (some statistical institutes already have some similar measurements but not with a good data cover). Some of the variables that we found were only available for some years or only for some countries. Commercialisation would be an interesting phenomenon to study more intensively. Commercialisation is not only about a direct economic profit but also about a gaining utility for the whole society - a welfare gain. The commercialisation process is important in many ways, if some innovations, say an environmental technological innovation is created, but it is too expensive for the local society or the individual person it might not increase the welfare in large. Of course not all innovations could not or should not be intended to result in a direct economic grain but the commercialisation process might make innovations more profitable for the society in large. The process could also, as we said before have a positive effect as an incentive for states to use some share of GDP to R&D. This research area is also something that might gain in getting more attention.

Acknowledging the political goals of the Lisbon strategy, that is to encourage innovations and a knowledge-based economy, we wanted our thesis to contribute to that discussion. The strong focus on R&D expenditure is something that could be questioned. Given the indications from our thesis it could be beneficial to focus on other parts of the innovation process; research productivity and commercialisation.

To sum up there are many things that would be interesting in study further and we think that the connection between innovation, commercialisation and economic growth will be important to put focus on in many years ahead.

7 Referenser

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8 Appendix

8.1 Appendix A

Growth rate in technology in the extended Romer model:

Technology accumulates as follows:

$\dot{A} = \bar{\delta} L_A \bar{I}$ (Equation 8)

where $\bar{\delta} = \delta^{\mu} A^{\phi/2} L_A^{\lambda-1}$ and $\bar{I} = I^{\gamma} A^{\phi/2}$

Which means that:

$\dot{A} = \delta^{\mu} A^{\phi/2} L_A^{\lambda-1} I^{\gamma} A^{\phi/2} L_A \quad \Leftrightarrow \quad \dot{A} = \delta^{\mu} A^{\phi} L_A^{\lambda} I^{\gamma}$ (Equation 11)

$$g_A = \frac{\dot{A}}{A} = \frac{\delta^{\mu} A^{\phi} L_A^{\lambda} I^{\gamma}}{A}$$

$g_A = \delta^{\mu} L_A^{\lambda} I^{\gamma} A^{\phi-1}$ (Equation 12)

By taking the logs and derivatives of the expression we find the expression for technological growth along a balanced growth path.

$$\ln g_A = \mu \ln \delta + \lambda \ln L_A + \gamma \ln I + (\phi - 1) \ln A$$

$$\frac{d \ln A}{dt} = \mu \frac{d \ln \delta}{dt} + \lambda \frac{d \ln L_A}{dt} + \gamma \frac{d \ln I}{dt} + (\phi - 1) \frac{d \ln A}{dt}$$

$$\frac{\dot{g}_A}{g_A} = \mu \frac{d\dot{\delta}}{\delta} + \lambda \frac{d\dot{L}_A}{L_A} + \gamma \frac{d\dot{I}}{\dot{I}} + (\phi - 1) \frac{d\dot{A}}{A}$$

$$\frac{\dot{g}_A}{g_A} = \mu g\delta + \lambda g L_A + \gamma g I + (\phi - 1) g_A$$

$\dot{g}_A = 0$ in equilibrium which leads to:

$$0 = \mu g\delta + \lambda g L_A + \gamma g I + (\phi - 1) g_A$$

$$-(\phi-1)g_A = \mu g\delta + \lambda gL_A + \gamma gI$$

$$gL_A = n$$

$$g_A = \frac{\mu g\delta + \lambda n + \gamma gI}{1-\phi}$$ (Equation 14)

Growth rate of GDP in steady state

GDP per capita:

$$y = k^{\alpha} A^{(1-\alpha)} \left(\frac{L_Y}{L}\right)^{(1-\alpha)}$$

$$\ln y = \alpha \ln k + (1-\alpha)\ln A + (1-\alpha)\ln \frac{L_Y}{L}$$

$$\frac{d\ln y}{dt} = \alpha \frac{d\ln k}{dt} + (1-\alpha)\frac{d\ln L_Y/L}{dt} + (1-\alpha)\frac{d\ln A}{dt}$$

$$gy = \alpha gk + (1-\alpha)g_A$$

Since $\frac{Y}{K}$ & $\frac{K}{L}$ are constant in equilibrium $gy = gk$ and gk can thus be substituted with gy in the equation below.

$$gy - \alpha gy = (1-\alpha)g_A$$

$$(1-\alpha)gy = (1-\alpha)g_A$$

$$g_y = g_A$$

Which means that:

$$g_y = g_k = g_A$$ (Equation 13)

Expression for GDP per capita in steady state

To find the expression for $\tilde{y}$ we use the production function and divide it with labour, L, and technology, A.

$$\frac{Y}{AL} = \frac{K^{\alpha}(AL_y)^{1-\alpha}}{AL}$$

$$\tilde{y} = \tilde{k}^{\alpha}\left(\frac{Ly}{L}\right)^{1-\alpha}$$

$$\tilde{k} = \frac{K}{AL} = \left(\frac{\dot{K}}{K} - \frac{\dot{A}}{A} - \frac{\dot{L}}{L}\right) = 0$$

$$\frac{K}{AL}\left(\frac{sY - dK}{K} - g_A - n\right) = 0$$

$$\frac{K}{AL}\left(\frac{Y}{K} - d - g_A - n\right) =$$

$$\frac{K}{AL}\left(s\frac{Y/AL}{K/AL} - g_A - n\right) = \tilde{k}\left(s\frac{\tilde{y}}{\tilde{k}} - d - g_A - n\right)$$

$\dot{\tilde{k}} = s\tilde{y} - (d + g_A + n)\tilde{k}$ is equal to 0 which leads to:

$$s\tilde{y}* = \tilde{k} * (d + g_A + n)$$

Put in the equation for $\tilde{y}$ like this:

$$s\tilde{k}^{\alpha}\left(\frac{L_Y}{L}\right)^{1-\alpha} = \tilde{k}(d + g_A + n)$$

$$\left(\frac{s}{(d + g_A + n)}\right)\left(\frac{L_Y}{L}\right)^{1-\alpha} = \frac{\tilde{k}}{\tilde{k}^{\alpha}}$$

$$\tilde{k}^{1-\alpha} = \left(\frac{s}{(d + g_A + n)}\right)\left(\frac{L_Y}{L}\right)^{1-\alpha}$$

$$\tilde{k}* = \left(\frac{s}{(d + gA + n)}\right)^{1-\alpha}\frac{L_Y}{L}$$

$$\tilde{y} = \tilde{k}^{\alpha}\left(\frac{L_Y}{L}\right)^{1-\alpha}$$

$$\tilde{y} = \left(\frac{s}{(d + g_A + n)}\right)^{\frac{\alpha}{1-\alpha}}\left(\frac{L_Y}{L}\right)^{\alpha}\left(\frac{L_Y}{L}\right)^{1-\alpha}$$

$$\widetilde{y} = \left(\frac{s}{(d + g_A + n)} \right)^{\frac{\alpha}{1-\alpha}} \left(\frac{L_Y}{L} \right)$$

$$y^* = \left(\frac{s}{(d + g_A + n)} \right)^{\frac{\alpha}{1-\alpha}} \left(\frac{L_Y}{L} \right) A$$

From the derivartion of the growth rate in technology we solve for technology as follows:

$$\frac{\dot{A}}{A} = \frac{\delta^{\mu} {L_A}^{\lambda} I^{\gamma} A^{\phi}}{A}$$

$$A = \frac{\delta^{\mu} {L_A}^{\lambda} I^{\gamma} A^{\phi}}{g_A}$$

Which gives us the final expression for GDP per capita in steady state

$$y^* = \left(\frac{s}{(d + g_A + n)} \right)^{\frac{\alpha}{1-\alpha}} \left(\frac{L_Y}{L} \right) \frac{\delta^{\mu} {L_A}^{\lambda} I^{\gamma} A^{\phi}}{g_A} \quad \text{(Equation 15)}$$

8.2 Appendix B

Variables for the productivity index

Variable	Definition	Source
Patent	Number of patent applications to the European Patent Office per million inhabitants.	Eurostat.
Internet	Number of internet users per 100 inhabitants.	Eurostat
CPI	Corruptions Perceptions Index.	Transparency International
Journal	Number of scientific and technical journals.	World Development Indicators (World Bank)
Trade	Trade as a percentage of GDP.	World Development Indicators (World Bank)
Kiss	Employment in Knowledge intensive service sectors as a percentage of GDP.	Eurostat
Emp	Employment rate by the highest level of education attained by the ISCED classification, levels 5 and 6 as a percentage of the population aged 25-64.	Eurostat

Variables for the commercialisation index

Variable	Definition	Source
Entrepreneurship	The share of people that prefer to be self-employed instead of employed.	The Eurobarometer 2000-2007
VC	Early stage venture capital investments and expansion and replacement venture capital investments as a percentage of GDP	Eurostat
Interest rate	Long term government bond yields, 10 years	Eurostat
GDP	Growth in GDP	Eurostat
FDI	FDI intensity	Eurostat

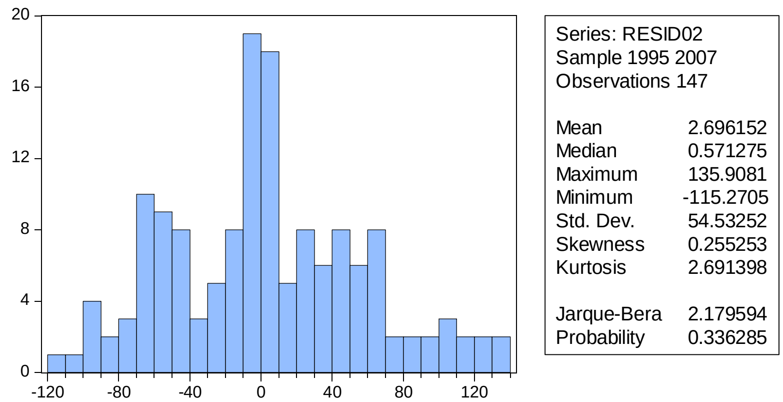
8.3 Appendix C

Tables for the productivity index

Correlations matrix

	PATENT	CPI	EMP	JOURNAL	KISS	TRADE	INTERNET
PATENT	1.000000	0.638234	0.122326	0.164030	0.619683	0.227199	0.488073
CPI	0.638234	1.000000	0.511897	-0.113942	0.765009	0.200913	0.545034
EMP	0.122326	0.511897	1.000000	-0.243834	0.401410	0.031734	0.410635
JOURNAL	0.164030	-0.113942	-0.243834	1.000000	0.010096	-0.396621	-0.020958
KISS	0.619683	0.765009	0.401410	0.010096	1.000000	0.230812	0.653760
TRADE	0.227199	0.200913	0.031734	-0.396621	0.230812	1.000000	0.103120
INTERNET	0.488073	0.545034	0.410635	-0.020958	0.653760	0.103120	1.000000

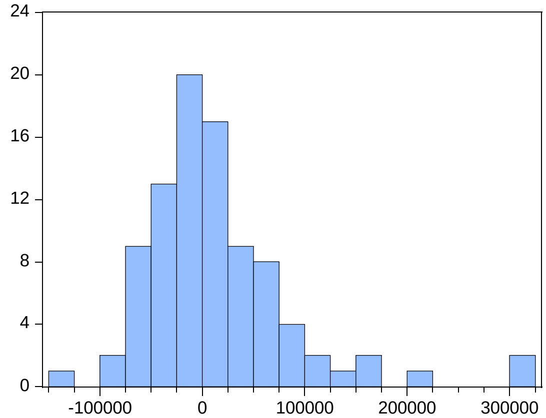
Histogram over the residuals



Tables for the commercialisation index

	BUSINESS	ENTR	FDI	GDP	INT	VC
BUSINESS	1.000000	0.107506	-0.142962	-0.066685	0.087001	0.527892
ENTR	0.107506	1.000000	-0.066065	0.228226	0.198729	-0.207143
FDI	-0.142962	-0.066065	1.000000	0.150897	-0.062676	-0.220280
GDP	-0.066685	0.228226	0.150897	1.000000	0.094902	0.077485
INT	0.087001	0.198729	-0.062676	0.094902	1.000000	0.186333
VC	0.527892	-0.207143	-0.220280	0.077485	0.186333	1.000000

Histogram over the residuals



Series: RESID02
Sample 1995 2007
Observations 91

Mean	14720.73
Median	2263.398
Maximum	310345.2
Minimum	-133776.3
Std. Dev.	72808.28
Skewness	1.774895
Kurtosis	7.791779
Jarque-Bera	134.8398
Probability	0.000000