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The optimal level of R&D
-the case of Sweden

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Abstract

Expenditures on R&D in Sweden are the highest of all OECD countries in relation to its GDP. The level of education in Sweden is also among the highest in the OECD area. But despite of this, growth rates of GDP and productivity in Sweden can be considered as average levels compared to similar economies. Therefore, this paper questions whether R&D efforts in Sweden are optimal in a social perspective. R&D efforts are in this context seen as partly R&D expenditures as a share of GDP and partly level of human capital in the R&D sector. This question is analyzed by applying endogenous growth theory which is a general theory of knowledge production. It takes advantage of a dynamic optimization model developed by Paul Romer and a regression analysis with a distributed lag model of knowledge production. The conclusions are that the actual time path of R&D expenditures as a share of GDP is in fact optimal, but that the time path of human capital in the R&D sector is roughly 40 percent higher than optimal. But the conclusion is also that this area of research is very complex and consequently this type of analysis has many shortcomings with unknown variables and parameters which make the results inexact. Therefore, many subjective assumptions must be made and these will to a large extent affect the outcome.

Keywords: R&D, human capital, productivity growth, endogenous growth theory, distributed lag model.

Contents

1. Introduction

In order to achieve economic growth in the long run, technological progress must take place. Technological progress, or knowledge production which is another term for it, is the main reason why the standard of living in developed countries has been raising so much over the past centuries. But technological progress does not come automatically; it is the result of economic activity in various forms. By producing goods, for example, people learn how to do it better and more efficiently. This is known as learning by doing.[1] Production of new knowledge may take place almost anywhere and at any time; in the production process of goods, in the service sector, in schools, in leisure time and perhaps even when a person is trying to fall asleep, just to name a few examples. These new ideas and knowledge then spread to other agents in the economy. In some economic activities, such as in universities and research and development (R&D) departments in firms, the objective is to create new ideas and new knowledge. In order to be successful, both in the goods producing and R&D sector, workers must also have adequate education. The question is then; how much resource should the society devote to R&D and education? It can be assumed that companies make this decision with the objective to maximize profits and cope with competition. But politicians decide how much resource to devote to research, universities and education, and can also affect the R&D climate in the society. This allocation between the goods producing sector and the R&D sector in Sweden is the focus of this paper.

The importance of growth rates is well known. What can be called the force of compounding means that even small changes in growth rates will have large effects on welfare in the long run.[2] Therefore, there will be large welfare benefits in the long run if growth rates can be increased, even if it is a marginal increase. One of the most important factors to economic growth is production of new knowledge. This can be seen by doing growth accounting which is an empirical method that decomposes GDP growth into different components, mainly growth rates of physical capital, labor and total factor

[1] Romer, D. (2001), p. 120
[2] Blanchard (1999), p. 193

productivity (TFP). TFP growth is also called the Solow residual and can be seen as anything other than growth of physical capital and labor that raises GDP per capita. TFP growth is often considered as technological change and this is the approach that will be followed in this paper. Then, it will be assumed that the level of productivity is the same as the level of technology. However, it should be noted that technological change may also refer to other factors, for example changes in rules.[3] Empirical results from growth accounting show that TFP growth stands for about 50 percent of the total GDP growth in high-income countries during 1947-1973. During 1960-1990 TFP growth decreased, and this phenomenon is known as the productivity growth slowdown.[4] That is, TFP growth has slowed down even though R&D activities have increased. This pattern is consequently a phenomenon not unique to Sweden, but it is more apparent there (see below). One need not take the productivity growth slowdown too seriously, however. Seen in an even longer perspective growth rates have not slowed down, they were just exceptionally high during the decades following the Second World War. It is nevertheless the case that "technological change lays at the heart of economic growth".[5]

Knowledge has some interesting characteristics. It is nonrival, which means that once an idea has been discovered it can be used by almost anyone. It is therefore very different from other types of goods, rival goods, which can be used by only one person at every point in time. Knowledge that has been discovered in one area may also be used in other areas in order to increase productivity. Except for patents, this process is almost costless; people just have to learn about the new technology and then take advantage of it. Knowledge therefore has important positive externalities that can increase welfare for everyone. It is also important to distinguish between different types of knowledge. Perhaps the most important difference is between basic and applied knowledge. Because basic knowledge is often difficult to use directly in the production process but may be an important prerequisite to it, it is mostly provided by the government. Applied research on the other hand, is often used by corporations solely for business interests.

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[3] Romer, D. (2001), p. 29
[4] Barro and Sala-i-Martin (1995), p. 350
[5] Romer, P. (1990), p. 72

As noted, technological progress is the result of economic activity in many parts of the economy, but of course, some parts may be more important than others. The level of education, or human capital to use the economic term for it, is closely linked to the R&D sector and in this paper human capital will be considered as an important part of that sector. In one perspective the R&D sector is the most obvious determinant to technological progress since research directly aims to affect it. Because of the favorable nature of ideas and knowledge one could easily think the more R&D in an economy the better, at least within some reasonable range. But that need not be the case, for several reasons. For example, the fact that knowledge is nonrival means that there is no guarantee that the advantages from it will stay within that particular country. There can also be diminishing marginal returns in the research process, so that it will be more and more difficult to create new knowledge when a lot has already been discovered. But nevertheless, R&D and education are important parts of modern economies and these parts are becoming larger. According to a report from OECD, expenditures on R&D have steadily increased in OECD countries since the 1980´s. This is especially true for Sweden, whose spending on R&D as a percentage of GDP is the highest among the OECD countries.[6] But despite of this, Sweden does not have a growth rate higher than normal, but can be seen as an average country in the OECD area. This raises some questions. Since R&D aims to produce new knowledge and knowledge is one of the main determinants to economic growth, the conclusion could be that Sweden is either devoting too much resource to R&D, or that the R&D process is not efficient. Therefore, this paper aims to investigate the nature of knowledge production in Sweden and whether the level of R&D efforts is socially optimal. This discussion leads to the question at issue.

The question at issue:

Are the relatively large R&D and education efforts in Sweden socially optimal?

This issue will be analyzed by applying endogenous growth theory, which is a theory of knowledge production. The focus of the theory is to explain the process of technological change by making the evolution of technology endogenous. This means that the theory

[6] Science and technology statistical compendium (2004), p. 9

explains the process of knowledge production within the model, it is not taken for granted. The specific model used in this paper is called “Endogenous technological change” and was developed by Paul Romer in 1990. The model shows how physical capital, labor and human capital are used to produce output and knowledge in equilibrium. A more general model of knowledge production developed by Paul Romer will also be used. The analysis will be done in several steps. First, information and data of the Swedish economy and relevant to these models will be collected. Some of the data must be worked up and transformed into variables that fit with the theoretical model. The data will then be used in a regression analysis that determines the relative contribution from different factors in the process of knowledge production. The regression will also help determining where the Swedish economy stands relative to its equilibrium. Finally, the Romer model will be used to determine the optimal level of R&D and education. This analysis and the regression analysis will be done with help of the statistical software Excel and EViews. Combining the results from the analysis will hopefully give an overview of knowledge production in Sweden and give an answer to the question above.

The focus of this paper is on technological process in Sweden. But technological progress is certainly affected by a large number of factors, so some demarcations are necessary. For example, patent laws can be important to endogenous growth and the social infrastructure will definitely be an important factor. Even though these factors may interact with technological change, they are not considered here. However, the R&D process in Sweden is not independent of the rest of the world, so a comparison with other countries is needed. Any country is both affected by and affecting the rest of the world in this process. Therefore it is necessary to compare data with similar countries to put the figures in perspective, but also to see how technology evolves outside Sweden. This “outside” technology will surely be important to R&D inside Sweden. A survey of this type can be done on different levels of analysis, for example case studies on particular industries or firms, or on the aggregate economy. This paper will be done by studying aggregate data rather than micro data. Of course, much can be learnt by studying individual industries or firms more thoroughly. But since this will be very time consuming, it is not in scope of this paper. Also, since different industries and sectors are affecting each other, much can be learnt by studying aggregate data and the aim is therefore to analyze how the Swedish economy performs on an aggregate level.

Since production of knowledge has a very complex nature, it is a quite difficult area of research. In all economic analyses it is necessary to make simplifications in order to isolate the problem that is considered. In endogenous growth theory this is perhaps even more apparent because many variables are either not known or have to be constructed or estimated. The interaction between variables is also complex and need not be directly observable. Knowledge is an abstract issue; there are no natural numbers to how much knowledge a country or a person has, it cannot be found in any statistical database. Therefore, one important challenge with this study is to construct realistic approximations to these variables that can be used in the analysis. The construction of these will be affected by subjective assumptions about how it should be done. Therefore, one has to realize that this type of study has its shortcomings and being aware of the assumptions underlying it. With other assumptions it is possible to come up with different conclusions. There is also a risk of following what has become the standard paradigm when studying a particular subject. That is, when studying R&D and technological change it is natural to start with endogenous growth theory because this is how it mostly is done. This is also how it is done here, but one need to be aware of that there may be alternative ways of analyzing technological change that are almost unthinkable.[7]

After this introduction a short review of current research in this area is presented. Then, in chapter 3, a theory of knowledge production and the Romer model are presented, which will be the foundation of the paper. Chapter 4 presents empirical facts of R&D in Sweden and some comparisons with similar countries. These facts will then be used in the analysis in chapter 5. It shows how these facts compare with the model's results. Finally, in chapter 6, conclusions will be drawn and discussed. The two appendices in the end show the technical details of the Romer model and the statistics used in the paper.

[7] Marsh and Furlong (2002), p. 24

2. Previous research

Endogenous growth theory is a relatively new area of research. It was developed in the late 1980´s and made technological progress endogenous by explaining how it evolves over time.[8] That is, endogenous growth theory can be seen as a general theory of technological change. But that technological progress is the main reason for economic growth in the long run had been known much earlier even though there was no universally accepted theory for it.

From the 1950´s, many case studies on industrial R&D expenditures and productivity growth were written. They tried to relate R&D expenditures to productivity growth in particular industries and had the disadvantage of not being generable to the whole economy. They focused on private returns of R&D rather than social returns.[9] But better econometric techniques and more open data sources led to a more formal and quantifiable analysis of this area. Zvi Griliches is one of the pioneers in using these methods in analyses of R&D and productivity. His studies, too, first focused on particular industries such as agriculture and manufacturing and tried to relate TFP growth to R&D expenditures, mainly on U.S. firms. His findings are that R&D expenditures have a relatively high rate of return; up to 30 % and that an estimate of the elasticity of output over R&D investments is 0.07. That is, 1 % increase in R&D expenditure will lead to 0.07 % increase in output. He found that basic research is more important than applied research and that privately financed R&D is more effective than publicly financed research.[10] In another study, Wang and Tsai studied manufacturing firms in Taiwan and they also found a significant relationship between R&D expenditure and TFP growth but a higher elasticity of around 0.18.[11] Griliches also did some comparative studies, comparing the R&D process in USA, France and Japan. He finds it hard to relate differences in TFP growth to the R&D process in different countries. But by comparing

[8] Romer, D. (2001), p. 8
[9] Griliches (1998), p. 3
[10] Ibid, p. 3-5
[11] Wang and Tsai (2003), p. 13

countries with different R&D intensities, these differences can be seen as an exogenous shift in R&D expenditures. The appearance of endogenous growth theory made it possible for him to focus more on spillover effects and R&D in imperfect markets. But he points out that there are many difficulties in this area of research; there are measurement problems and different sectors show different patterns which makes it hard to draw general conclusions. Therefore, the estimates will be highly uncertain and our knowledge in this area is still very limited.[12]

In the introduction the productivity growth slowdown was discussed. In recent years, however, productivity growth has turned around again and has increased since the second half of the 1990´s. Baso, Fernald and Shapiro show in an NBER working paper that this increase in productivity growth stems from increased technological change and not from higher factor utilization, capital accumulation or returns to scale.[13] Another interesting issue in this area is the time structure in the production of new knowledge. Balcombe, Bailey and Fraser ran regressions on the U.S. and the U.K. economies using a distributed lag model. They found limited support for the importance of R&D and that a reasonable lag length for these economies is 9 to 10 years.[14]

This short review of previous research is of course not complete, but shows some of the results found by other studies. The results are somewhat mixed, but on the whole there seems to exist significant relationships between R&D expenditures and TFP growth. One reason for the mixed results is that different methods are used and sometimes different methods are used in the same study to look for the method that fits best. No satisfactory study on this subject was found on the Swedish economy. The hope is therefore that this paper can shed some new light in this area.

[12] Griliches (1998), p. 5-10
[13] Basu, Fernald and Shapiro (2001), p. 35
[14] Balcombe, Bailey and Fraser (2005), p. 68-70

3. Endogenous growth theory

The focus of the neoclassical growth theory before the 1980´s was to show how accumulation of physical capital, a growing labor force and an exogenously determined technological progress interact to increase output per capita over time. That is, technological progress was not explained but just taken for granted. The endogenous variable was physical capital, and the theory explained how this variable evolved when investment ratios changed, holding other parameters fixed. However, physical capital eventually runs into diminishing marginal returns, so it cannot explain the huge growth of output per capita in the long run. Therefore, the only variable that is able to explain economic growth in the long run is technological progress. The aim of new growth theory is to explain this process. The theory makes technological progress endogenous by explaining how it evolves over time. New growth theory, or endogenous growth theory as it is also called, was pioneered by Paul Romer in 1990. Technological progress may mean many things; it can be seen as anything other than physical capital and labor that increases output in the economy. For example, a more favorable law that makes it easier for firms to make investments can be seen as technological progress.[15] However, the focus in this paper is on production of knowledge and accumulation of human capital. This chapter presents the theory of endogenous growth. It first presents a general theory of knowledge production which will be used in the regression analysis to determine the relative contribution from different factors in the process of knowledge production. Then it presents the Romer model which will be used to determine the optimal level of R&D.

3.1 Knowledge production

Above it was noted that technological progress is made endogenous by explaining how it evolves over time. This can be done by describing mathematically how different variables interact and affect the process of knowledge production. The level of

[15] The Economist (May, 20th -26th, 2006), p. 84

knowledge is in this case just the same as the level of technology. At every point in time the economy has a certain amount of knowledge available, or a specific level of technology. The economy can be described by conventional production functions for both output and knowledge. That is, both output and knowledge are produced by using physical capital, labor and the available level of technology. General production functions for output and knowledge is suggested by P. Romer (1990), Grossman and Helpman (1991) and by Aghion and Howitt (1992) and are ordinary Cobb-Douglas production functions.[16] The production function for output Y at time t in the economy is described by

$$Y(t) = \left((1 - a_K)K(t)\right)^{\alpha} \left(A(t)(1 - a_L)L(t)\right)^{1-\alpha}, \; 0 < \alpha < 1. \tag{3.1}$$

In this function, a_K and a_L are the shares of the economy's total resources of physical capital and labor that are used in the R&D sector. That is, the larger these shares are, the more resources are taken away from the goods producing sector. K and L stand for physical capital and labor and A stands for the level of technology. The relative importance of physical capital in goods production is reflected by α. This parameter is assumed to be a number between 0 and 1 which means that the production function has constant returns to scale in the two variables K and AL. If these two variables are doubled, output Y is doubled as well. As noted above, knowledge is produced by using physical capital, labor and the available level of technology. Then, the change in technology at time t is described by $\dot{A}(t)$ which is just a shorthand notation for the derivative of A with respect to time, dA/dt. In the same way the change in the physical capital stock at time t is described by $\dot{K}(t)$. It is assumed that a fraction s of output Y is invested in the physical capital stock and also that this stock does not depreciate. Therefore, the change in the physical capital stock is just output multiplied by the fraction s. The functions that describe how A and K change at time t are called the equations of motion and have the specific forms

$$\dot{A}(t) = B\left(a_K K(t)\right)^{\beta} \left(a_L L(t)\right)^{\omega} A(t)^{\theta}, \; B > 0, \; \beta \geq 0, \; \omega \geq 0 \tag{3.2}$$

[16] Romer, D. (2001), p. 100

$$\dot{K}(t) = sY(t) = s(1-a_K)^{\alpha}(1-a_L)^{1-\alpha} K(t)^{\alpha} A(t)^{1-\alpha} L(t)^{1-\alpha} \;. \tag{3.3}$$

In equation (3.2), B measures anything other than physical capital, labor and technology that determines the production of knowledge. θ measures the effect of the existing amount of knowledge on production of new knowledge. Contrary to what is often assumed for production functions for output (for example in equation (3.1)), the production function for knowledge needs not have constant returns to scale. Instead, both decreasing and increasing returns to scale are possible and therefore, the sum of the exponents in this function is not necessarily one. In equation (3.3), the expression for Y in equation (3.1) is just multiplied by s and then simplified. Equations (3.2) and (3.3) describe the change in A and K, independent of their absolute levels. In order to find the growth rates, each expression has to be divided by A and K respectively. Defining $c_A = Ba_K^{\beta} a_L^{\omega}$ and $c_K = s(1-a_K)^{\alpha}(1-a_L)^{1-\alpha}$, (3.2) and (3.3) give the growth rates of technology and physical capital

$$g_A(t) = \frac{\dot{A}(t)}{A(t)} = c_A K(t)^{\beta} L(t)^{\omega} A(t)^{\theta-1} \tag{3.4}$$

$$g_K(t) = \frac{\dot{K}(t)}{K(t)} = c_K \left(\frac{A(t)L(t)}{K(t)} \right)^{1-\alpha} \tag{3.5}$$

By taking logs of each side of equations (3.4) and (3.5) and using the mathematical rules for logarithms the following expressions can be generated

$$\ln(g_A(t)) = \ln(c_A) + \beta \ln(K(t)) + \omega \ln(L(t)) + (\theta - 1)\ln(A(t)) \tag{3.6}$$

$$\ln(g_K(t)) = \ln(c_K) + (1-\alpha)(\ln(A(t)) + \ln(L(t)) - \ln(K(t))) \tag{3.7}$$

Applying some basic mathematical rules, it can be shown that the time derivative of the logarithm of a variable equals the growth rate of that variable.[17] Then, by using this fact, the growth rates of the growth rates of technology and physical capital are given by taking the derivative of equations (3.6) and (3.7) with respect to time. Because c_A and c_K are constants, their derivatives equal zero and drop out. Following this approach gives the growth rates of the growth rates of technology and physical capital according to

[17] $\frac{d \ln X(t)}{dt} = \frac{1}{X(t)} \frac{dX(t)}{dt} = \frac{\dot{X}(t)}{X(t)}$

$$\frac{\dot{g}_A(t)}{g_A(t)} = \beta g_K(t) + \omega n + (\theta - 1) g_A(t) \tag{3.8}$$

$$\frac{\dot{g}_K(t)}{g_K(t)} = (1-\alpha)\big(g_A(t) + n - g_K(t)\big), \tag{3.9}$$

where n stands for the growth rate of L. Equations (3.8) and (3.9) are the key functions that will be used in the regression analysis. They represent the economic model which will be transformed into an econometric model in chapter 5. Also, they can be used to determine where the economy stands relative to its equilibrium. How this is done is further described in chapter 5. The dynamic optimization model that will be used to determine the optimal level of R&D, the Romer model, is presented in next section.

3.2 The Romer model

The Romer model of endogenous technological change is a so called dynamic optimization model. This means that the objective is to optimize at each point in time; finding an optimal time path and not just a single static optimal value.[18] Then, optimal values can be described by a times series diagram showing the optimal values as a function of time. How this is done will be shown later. The model was developed by Paul Romer in 1990 and is presented by Chiang (1992).[19] The model has many details and derivations and these are therefore described in appendix 1. However, the final results of the model are the most relevant for this paper.

As in the production function for knowledge above, the Romer model divides the economy into two sectors, one goods producing sector and one R&D sector where new ideas and knowledge are produced. In contrast to neoclassical growth theory, the focus is mainly on the latter sector and describes how production of ideas and knowledge evolves. One important variable left out in the production functions for knowledge above is human capital. Human capital is the amount of skills and knowledge that a specific

[18] Chiang (1992), p. 3
[19] Ibid, p. 269-274

person has.[20] The skills and knowledge for persons working in the R&D sector will of course be an important determinant to success in R&D. But this will also be important to persons working in the goods producing and service sectors since much innovative activities take place there as well. Because governments are the main providers of education they can affect the level of human capital. A model of knowledge production which includes human capital is therefore needed. The model presented in this section does that and determines the optimal level of human capital in the R&D sector and the evolution of the variables in steady state. It can therefore be seen as a model that tells us how much resource devoted to the R&D sector that is optimal in the long run. Knowledge consists in two forms, human capital and technology. Technology is nonrival and can therefore be used by anyone in the economy. Because of this, there are important externalities. The other form of knowledge, human capital, belongs to specific persons, that is, the skills and education workers have. This type of knowledge is rival because it is only that particular person who can use this type of knowledge. The sum of all persons´ human capital is the total amount of human capital in the economy and is denoted S_0. It is the sum of S_Y and S_A, which is human capital in the goods- and knowledge producing (R&D) sectors respectively. The production function for goods *Y* in the economy is

$$Y = S_Y^{\alpha} L_0^{\beta} \int_0^A x(i)^{1-\alpha-\beta} \, di \,, \tag{3.10}$$

where the inputs are human capital, labor and physical capital. The exponents measure the "importance" of each input in the production process. In equation (3.10), $x(i)$ means different designs of physical capital used in the production process. The design of physical capital is a somewhat obscure concept, but it can be thought of as different types of machines. For example, if a new and better type of computer is invented it can be regarded as an additional design of physical capital. The higher level of technology *A* an economy has, the more designs there are. The integral sign illustrates this; it means that all $x(i)$:s are summed between *0* and A. However, all types of designs are assumed to have a common level $\bar{x}$ that describes all different types of $x(i)$. Furthermore, γ is a parameter that tells how many units of capital goods are needed to produce one unit of

[20] Romer, D. (2001), p. 133

design of physical capital. Therefore, the total amount of physical capital in the economy is $K = \gamma A \bar{x}$. Putting these facts together, production function (3.10) can also be written

$$Y = S_Y^{\alpha} L_0^{\beta} A^{\alpha+\beta} K^{1-\alpha-\beta} \gamma^{\alpha+\beta-1} \tag{3.11}$$

As in the production functions in previous section, there is no depreciation, so investments are just output less consumption. Using the definition $S_0 = S_Y + S_A$ and production function (3.11), the equation of motion for physical capital becomes

$$\dot{K} = (S_0 - S_A)^{\alpha} L_0^{\beta} A^{\alpha+\beta} K^{1-\alpha-\beta} \gamma^{\alpha+\beta-1} - C . \tag{3.12}$$

The production function for knowledge is simpler than in previous section since it ignores the role of physical capital. The specific function used in this model is

$$\dot{A} = S_A \sigma A \Rightarrow g_A = \frac{\dot{A}}{A} = S_A \sigma , \tag{3.13}$$

which is called the equation of motion for technology. In this function the productivity growth rate is proportional to the level of human capital and σ is the research success parameter. That is, the higher σ , the more productive the process is. Equation (3.13) is actually a modified version of a more general production function for knowledge

$$\dot{A} = a_Y \sigma A - \delta A \Rightarrow g_A = \frac{\dot{A}}{A} = a_Y \sigma - \delta , \tag{3.14}$$

where a_Y is the share of output devoted to R&D and δ is the rate at which knowledge depreciates.[21] Then, both human capital in the R&D sector and the share of GDP devoted to R&D can be regarded as inputs into the knowledge production process. Furthermore, function (3.13) assumes that $\delta = 0$. However, what gives people welfare is not knowledge per se, but consumption. Therefore, the objective of the model is to maximize utility that people gets from consumption. The utility function for consumption is assumed to have the form

$$U(C) = \frac{C^{1-\varphi}}{1-\varphi} , \tag{3.15}$$

[21] Chiang (1992), p. 268-269

where C is consumption and φ reflects the relative risk aversion, that is, people's willingness to shift consumption between different time periods. Combining (3.15), (3.13) and (3.12), the social maximization problem for this model is

$$\text{Max} \int_0^\infty \frac{C^{1-\varphi}}{1-\varphi} e^{-\rho t} dt$$

$$\text{subject to } \begin{cases} \dot{A} = S_A \sigma A \\ \dot{K} = (S_0 - S_A)^\alpha L_0^\beta A^{\alpha+\beta} K^{1-\alpha-\beta} \gamma^{\alpha+\beta-1} - C \end{cases} \tag{3.16}$$

$$\text{and } A(0) = A_0,\ K(0) = K_0,$$

which is a common type of maximization problem in economics where the objective is to maximize a variable (in this case utility from consumption) subject to some constraints (in this case the equations of motion for technology and physical capital). The last line shows initial values of knowledge and physical capital. The first equation in (3.16) means that the objective is to maximize utility from consumption with an infinite time horizon and in this function, ρ stands for the discount rate. The solution of (3.16) is given as the steady state value of human capital in the R&D sector

$$S_A = \frac{\sigma(\alpha + \beta)S_0 - \alpha\rho}{\sigma(\alpha\varphi + \beta)} \tag{3.17}$$

Using the production function for knowledge (3.13), steady state growth rates are then given by

$$\frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \frac{\dot{C}}{C} = \frac{\dot{A}}{A} = \frac{\sigma(\alpha + \beta)S_0 - \alpha\rho}{\alpha\varphi + \beta} \tag{3.18}$$

It is then assumed that GDP, physical capital, consumption and technology grow at the same rate in steady state. Equations (3.17) and (3.18) are some of the key functions that will be used in the analysis in chapter 5. This completes the presentation of the theoretical models. In the following chapter the empirical findings relevant to this study are presented. It shows data for the variables used in the models and how these data are constructed. The empirical findings will also be used in the analysis in chapter 5.

4. Empirical facts

This chapter presents empirical facts of the variables relevant to this survey. It aims to give an overview of the R&D sector in Sweden and some comparisons with other countries. This comparison is needed because the R&D process in Sweden cannot be seen in isolation, independent of other economies. The chapter shows how much resources are devoted to R&D, how the level of productivity has changed and also how much human capital there is in both sectors. These empirical facts are needed in the regression analysis and when comparing with the Romer model in chapter 5. That is, the information in this chapter will both give a descriptive picture of the Swedish economy but also be the building ground for the analysis in the following chapter. However, it is not always clear how the data should be collected and worked up, so first, a discussion on this issue follows.

Lack of relevant data is always an apparent problem in social sciences, and this area of research is no exception. Much can be found in all fine databases, but not everything. There are basically two problems with the data available in such databases. First, variables used in theoretical models are not exactly the same as are found in databases. Theoretical models represent “ideal” worlds where there is only one interpretation of each variable. But in reality, a variable can be measured in many different ways. For example, aggregate output can be measured in various ways. In sectors as health, defence and many service sectors there are no output values to use. One has to rely on input values, which are often measured as cost indices. These sectors are often high-tech industries where much R&D takes place.[22] This will lead to measurement errors. Other variables specified in a theoretical model cannot be found at all. For example, there are no statistics on human capital as it is presented in chapter 3. Instead, other observable variables affecting the level of human capital must be used to create this variable in a reasonable way. The other problem is that there are missing observations; individual years or longer time periods. In growth theory we are usually interested in the evolution

[22] Griliches (1998), p. 19-22

of the economy in the long run which requires historical data. It becomes harder and harder to find relevant data the more backward in time we go. But on the other hand, the recent past is most relevant. The way a specific variable is measured may also have changed over time, making comparisons between the two data series misleading.

In order to overcome these problems and to get numerical results, some of the data series have to be constructed and estimated, sometimes using more than one data source. The sources used in this paper are shown in appendix 2 and are mainly Statistics Sweden (SCB), World Development Indicators, OECD and the website historia.se. In each section of this chapter it is explained how these sources are used to construct the series. Since it is not obvious how this should be done, subjective considerations will affect the final result. There are certainly different views of how this should be done and what reasonable assumptions are. It is therefore important being aware of the assumptions underlying the analysis when evaluating the results. Another thing worth noting is that the focus is on observable data and observable relationships between variables. But economic growth is a very complex phenomenon, so there may be unobservable relationships that are important but are not included in the analysis.[23] These epistemological considerations are crucial for a complete understanding of the subject. Having completed this discussion on possible measurement errors it is time to move on to the empirical facts, starting with an international comparison. After that empirical facts particular to Sweden are presented.

4.1 An international comparison

What is happening to an economy is as described above not independent of the other world. This section therefore presents a comparison with countries similar to Sweden. By similar it is meant countries that can be thought of having roughly the same balanced growth paths, that is, high income OECD countries. These countries are relatively

[23] Marsh and Furlong (2002), p. 20

homogenous.[24] Since knowledge is a nonrival good and Sweden is an open economy, the R&D process in Sweden cannot be seen in isolation, independent of the rest of the world. R&D in Sweden will generate externalities that benefit not just the Swedish economy, but also other economies. The Swedish economy will also benefit from R&D in the rest of the world. This international comparison will make it easier to put the empirical findings and the numerical results from the analysis in perspective, to tell whether facts about Sweden are good or bad, compared to similar countries. It will also show how the Swedish R&D sector differs from R&D sectors in other countries.

4.1.1 R&D efforts and growth rates

In the introduction it was argued that Sweden does not have a growth rate higher than normal, despite the fact that the relative size of its R&D sector is among the largest in the world. Figure 4.1 shows this pattern. It presents two scatter plots with real GPD growth on the y-axis and R&D expenditure as a percentage of GDP and researchers per million people respectively, on the x-axis. As was also noted in the introduction this could mean that Sweden is either devoting too much resource to the R&D sector or that this sector is inefficient. This could in turn have many possible explanations which will be discussed further in chapter 5.

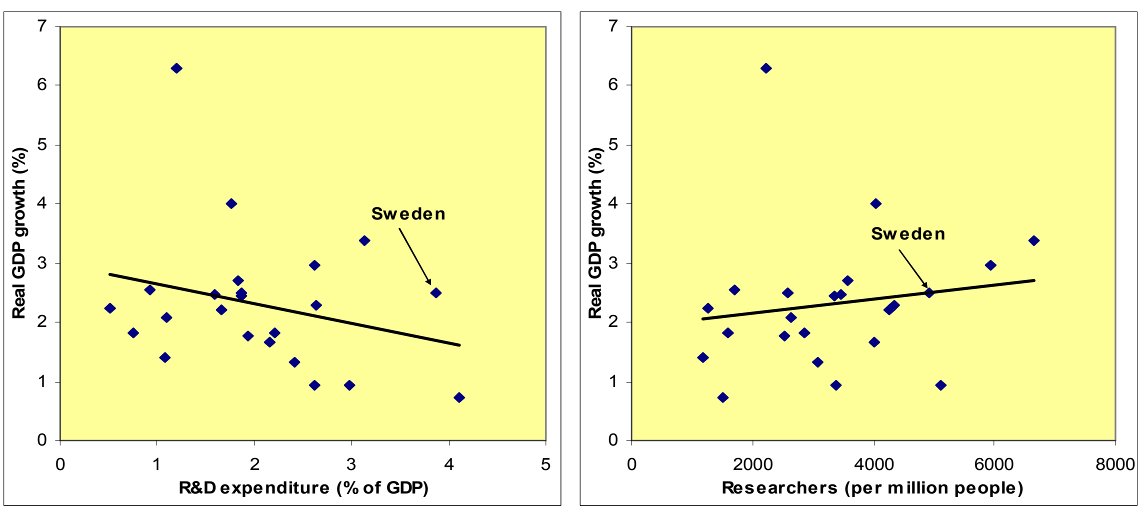

Figure 4.1: Real GDP growth and R&D expenditure as a percentage of GPD/researchers per million people in OECD countries. Mean 1996-2004.[25]

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[24] Barro and Sala-i-Martin (1995), p. 7

[25] World Development Indicators, http://devdata.worldbank.org/data- (2006-09-20). Countries in comparison: Australia, Canada, Denmark, Finland, France, Germany, Hong Kong, Iceland, Ireland, Israel,

During the last decade Sweden has spent around 4 percent of its GDP on R&D. This is far above the mean of European Union members which had a mean of 1.9 percent in 2001. The European Union has set up the so called Lisabon target that says that the mean in EU should be 3 percent by the year 2010.[26] What can also be seen in figure 4.1 is that there are no clear relationships either between output growth and R&D expenditures or between output growth and the amount of researches. The fitted regression lines shown in the figures are

$$\begin{aligned} g_y &= 2.99 - 0.33E \\ g_y &= 1.90 + 0.0001R \end{aligned} \tag{4.1}$$

where g_y is the growth rate of real GDP, E is R&D expenditures and R is researchers per million people. The regression, if anything, actually shows that output growth depends negatively on R&D expenditures and that the growth rate is essentially independent of the amount of researchers per million people. However, the coefficient of determination, R^2, is almost zero, so the predictive ability of the regressions is very limited.[27]

4.1.2 Composition of the R&D sector

The composition of the Swedish R&D sector also has some interesting characteristics compared to other OECD countries. The business sector in Sweden stood for almost 80 percent of total R&D expenditures in 2002 and this share, too, was the highest of all the countries compared. Swedish business enterprises spent more than 5 percent of its value added on R&D which is far above the OECD mean of a full 2 percent. The government on the other hand, stands for a relatively small share of the total R&D expenditures.[28] This is worth noting, since Sweden is often known for its large public sector.

4.1.3 Human capital

The level of human capital is also high in Sweden compared to similar countries, even though it is not the highest among them. The level of education is the most common way

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Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom and the United States.

[26] Science and technology statistical compendium (2004), p. 7

[27] Hill, Griffiths and Judge (2001), p. 124

[28] Science and technology statistical compendium (2004), p. 10-12

to measure human capital. The percentage of the population who has a tertiary-level education was almost 30 percent in 2002, compared to 23 percent in the OECD area. Only Canada, Japan and the United States had a higher share. Expenditure per student on that level of education was top 3, beaten by only United States and Switzerland.[29] These figures, however, do not say anything about the educational quality or efficiency of the educational system but it is an approximation to differences in the level of human capital. The evolution of human capital in Sweden is further discussed in section 4.4.

4.1.4 Productivity

In the growth theories presented in chapter 3, one of the key variables is technology, or knowledge. The theories show how A, the total amount of knowledge in the economy changes according to the production functions specified. Technological change can then be measured as the change in total factor productivity.[30] That is, it is assumed that change in productivity is a good approximation to technological change. Productivity then, is usually measured as output per some amount of input.[31] Input may be total labor force or total hours worked, but other measures are also possible. However, hours worked can be seen as the most accurate measure of input on the grounds that is tells how much will be produced in a specified amount of time worked. Using labor force as input could give misleading numbers. For example, if a country has a large labor force, but in which each worker is not working so many hours per day, this will result in a too low level of productivity.

Figure 4.2 compares productivity growth rates in the G7 countries and Sweden since 1970. Productivity is measured as GPD per hour worked. Values are logged and given the same value in 1970 in order to more clearly show differences in growth rates. When values are logged the slope of the lines equals their growth rates. The diagram shows that for most of the period Sweden has had a slower productivity growth rate than the G7 countries, but in recent years it has been the other way around. Table 4.1 compares absolute values in productivity levels among some selected economies, also by using

[29] Science and technology statistical compendium (2004), p. 22
[30] Griliches (1998), p. 1
[31] Ibid, p. 18

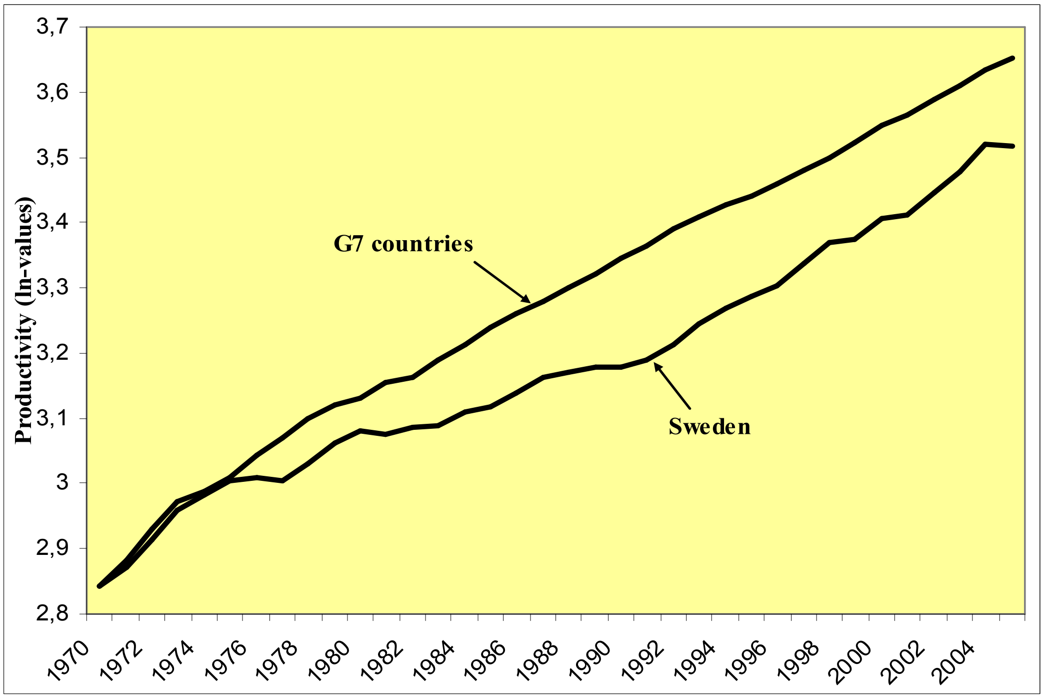

Figure 4.2: Productivity level in the G7 countries and in Sweden.[32]

Sweden	United States	OECD	EU	Denmark	Finland	Norway	Japan
89	**100**	**75**	**80**	**89**	**83**	**129**	**70**

Table 4.1: GDP per hour worked 2004. Index, United States = 100.[33]

output per hour worked. Here, Sweden can be said to be in the middle range. Comparing figure 4.2 and table 4.1 could be a little confusing. Diagram 4.2 shows that the OECD area has a higher level of productivity in absolute terms, but table 4.1 tells the other way around. But it should be remembered that they use different definitions and perhaps also different measures of output. Instead, looking at each of them alone, they have something to offer. The first compares growth rates, the second absolute levels. After this brief comparison with other countries the rest of the chapter presents empirical facts particular to Sweden. The following section shows how the key variables of the theoretical models have evolved on the balanced growth path.

[32] OECD Productivity database (September 2006), http://www.oecd.org/topicstatsportal/0,2647,en_2825_30453906_1_1_1_1_1,00.html (2007-01-20)
[33] Ibid

4.2 The balanced growth path

The balanced growth path is the long run equilibrium in which the variables are growing at constant rates.[34] Steady state is a related concept in which all variables are growing at the same rate.[35] Steady state in the Romer model is given by

$$\frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \frac{\dot{C}}{C} = \frac{\dot{A}}{A}. \qquad (4.2)$$

The growth rates of each these variables are presented in figure 4.3. Taking the geometric mean of the corresponding data series the balanced growth path is given in table 4.2.

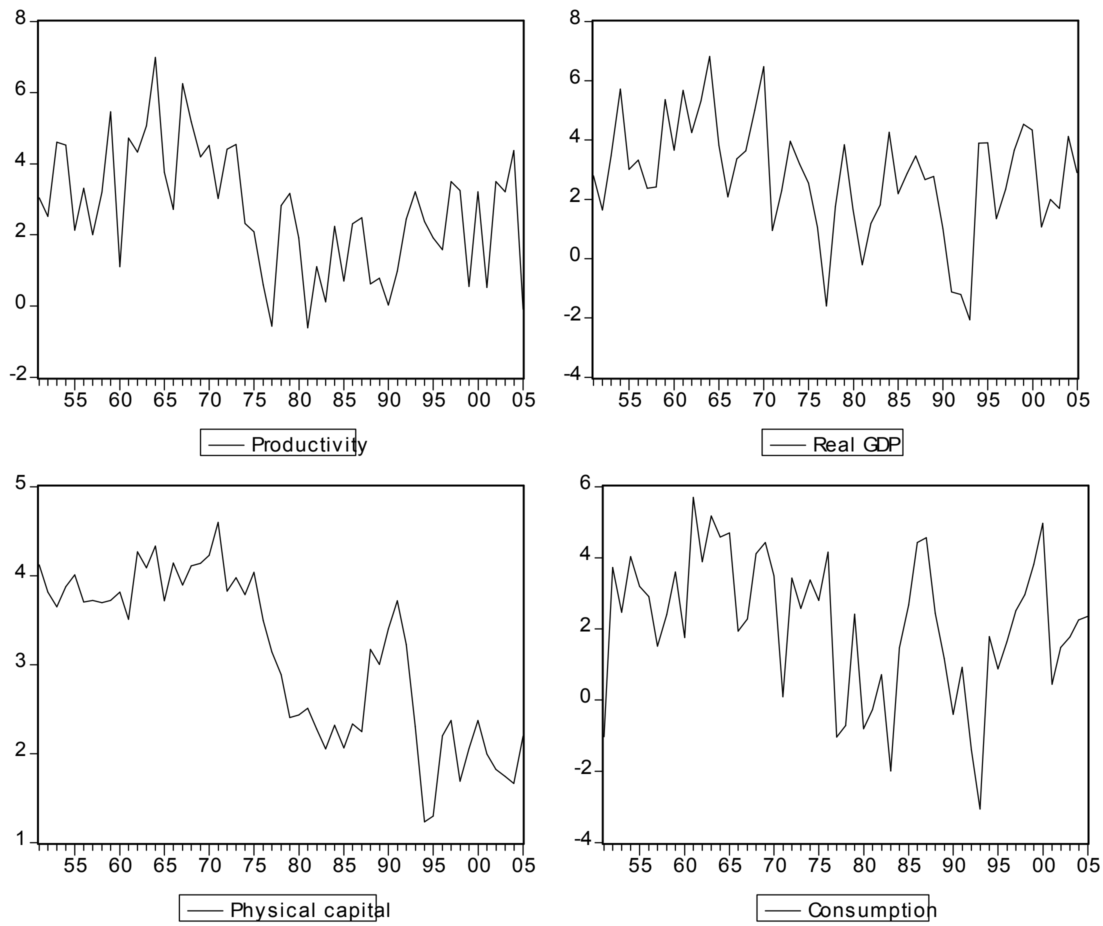

Figure 4.3: Annual growth rates of productivity, real GDP, physical capital and consumption 1950-2005.[36]

[34] Romer, D. (2001), p. 16-17
[35] Chiang (1992), p. 273
[36] SCB, Statistiska meddelanden, historia.se and Konjunkturinstitutet

	Annual growth rate (%)
Productivity	**2,68**
Real GDP	**2,77**
Physical capital	**3,09**
Consumption	**2,25**
Steady state	**2,70**

Table 4.2: The balanced growth path.

4.2.1 GDP, physical capital and consumption

As can be seen in table 4.2, physical capital has been growing at the highest rate and consumption at the lowest. Since steady state is defined as a common rate at which all variables are growing, it is here assumed to be the mean of the all the growth rates, that is 2.70 percent annually. GDP, physical capital and consumption are measured as aggregate numbers which follows the Romer model. They are all adjusted for inflation. Because no complete data series was found, both physical capital and consumption are constructed from two different data series. Data on physical capital 1950-1994 comes from the German economist Albrecht Ritschl who used data from SCB. This series is then extended by a more recent series on the physical capital stock from SCB. Data on consumption comes from Konjunkturinstitutet back to 1980 and the years before that from historia.se. Both the consumption and physical capital series have then been calculated as unitary series so that they are comparable. This has been made by starting from one of the series which then, by help of index numbers form the other series, has been expanded to series that covers the whole period.

4.2.2 Productivity

One of the key variables in this paper is productivity and this is also shown in figure 4.3. In section 4.1.4 a productivity comparison between Sweden and the OECD area was made. It was argued that the best measure of productivity is output per hour worked and this is what is used here as well. Output is straightforward to measure, it is real GDP. Total hours worked, on the other hand, can be measured in several ways. Some statistical data sources use total hours per week and some use total hours for the whole year. In order to get as long data series as desired, data sets from both SCB and historia.se have been used. From these two sources, a unitary measure of hours worked has been constructed as an index. Then, productivity calculated as real GDP over hours worked has grown as shown in figure 4.3. In this diagram, the productivity growth slowdown can be seen from the beginning of the 1970´s. However, from the beginning of the 1990´s productivity growth rates have been little higher again.

4.3 Resources devoted to R&D

This paper questions the relatively large R&D efforts in Sweden and this section looks more closely how the shares of total resources devoted to R&D have evolved over time. In the introduction and in section 4.1.1 it was argued that Sweden is devoting much resource to R&D compared to similar countries. As was also noted earlier, resources devoted to R&D can be split into R&D expenditure as a percentage of GDP and share of the labor force who is working in the R&D sector. Whether these shares are optimal or not will be analyzed in next chapter. However, the shares presented here do not have exactly the same interpretation as in the models used in this paper. The Romer model determines the optimal level of human capital in the R&D sector, not the share of the labor force working in the R&D sector. But both measures are related and the latter is presented here to give a descriptive and comparable view or the R&D sector. Human capital is presented in next section. Figure 4.4 shows how R&D expenditure as a percentage of GDP and the share of the labor force working in the R&D sector have evolved since the 1980´s. As can be seen in the figure, the shares have steadily increased. But in the last years, the share of GDP devoted to R&D has actually decreased. What is also clear is that the share of GDP devoted to R&D is much larger than the share of the labor force that is working in the R&D sector. Data on R&D expenditure as a percentage of GDP is directly available from SCB, but data on the share of the labor force working in the R&D sector was found only for some individual years. The whole time series for this variable has then been constructed. For the last time period, there is data available, but in the years before 1995 it is assumed to follow R&D expenditure as a percentage of GDP. It is then assumed that, when the society as a whole is devoting more resources to R&D, this is done by increasing expenditure and R&D personal in the same proportion.

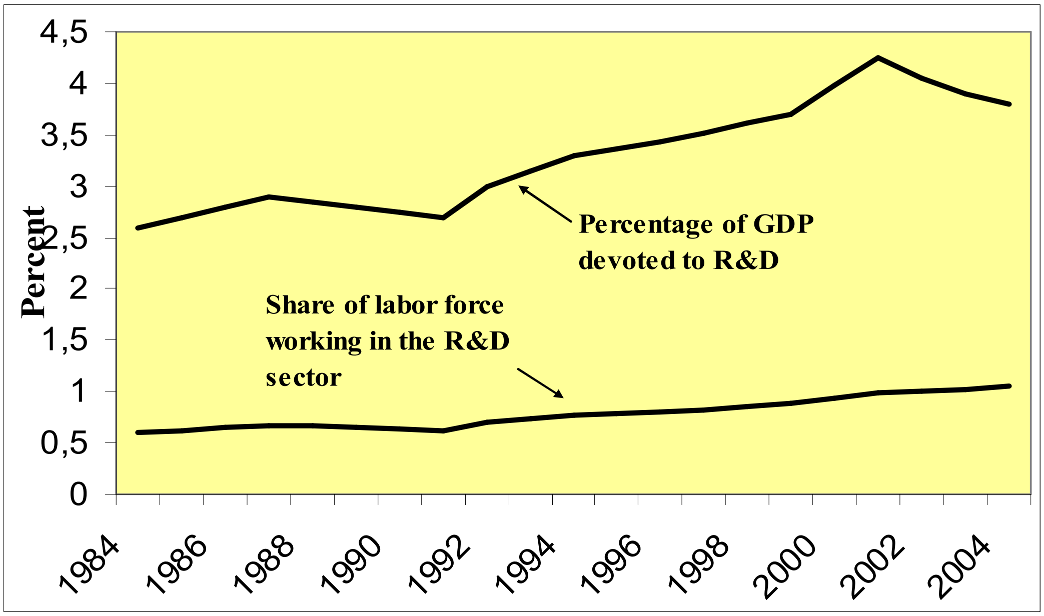

Figure 4.4: Resources devoted to the R&D sector.[37]

As noted, the Romer model does not include the share of labor force working in the R&D sector. Instead, human capital in the R&D sector is used. Therefore, the evolution of human capital will now be investigated further.

4.4 Human capital

According to the Romer model, knowledge consists of two parts, technology and human capital. Technology, the nonrival part, is in this paper measured as productivity and presented in section 4.2.2. The other part, human capital, is rival and specific to individual workers. It is rival because a worker's knowledge and skills can be used at only one place at every point in time. When this worker exits the economy, that worker's human capital is lost. Further, the Romer model distinguishes between human capital in the total economy and in the R&D sector. This section shows how the constructions of these two indices of human capital have been made but first some general considerations relevant to both sectors are discussed.

[37] SCB and World Development Indicators

4.4.1 General considerations

Human capital is a somewhat obscure concept. In growth theory, human capital is defined as the acquired knowledge, skills and abilities that individual persons have.[38] The more human capital a person has, the more productive this person is in the production process and adds more value. But there is no natural way of measuring human capital as it is defined in growth theory. Accordingly, it does not exist in the official statistics. What does exist in the official statistics is the average level of schooling and education and these statistics can be used to measure the level of human capital. As noted earlier, this is the usual way of measuring human capital.[39] But there are some important drawbacks of using these statistics as the level of human capital. First, these statistics represent only formal education. People learn outside school as well. When people work, they get more experienced and learn new skills. They may even learn during leisure time. And different persons do not have the same ability to learn, disregarding their level of schooling.

If workers get additional education from their employer it will increase their level of human capital. Further, because of this, workers may get more inspired, happy to learn new skills. If the job is more varied, they might also learn different tasks and feel happier about their job. This will probably affect the level of human capital in a positive way. On the other hand, in a more dynamic labor market, workers more frequently move between different jobs. This will make them beginners in their job more often. Sometimes it will take much time to learn a new job, especially a more skill-demanding one, and makes the workers relatively inefficient during that time. Sticking with one job for a long time will give the worker much skill, but only in that particular kind of job. Frequently switching between different jobs may give additional views of how things could be done, perhaps in a more efficient way. Nowadays it is very easy to communicate with other people and get information quickly. Then, new technology may spread faster between different places of work and the previous discussed effects of externalities may be larger. This may affect both the level of human capital for individual workers, but also the technological level in the economy.

[38] Romer, D. (2001), p. 133
[39] Science and technology statistical compendium (2004), p. 22

All these factors are important to the level of human capital, but they are difficult to measure. However, it seems reasonable to expect that the total effect from the factors above to be positive. But on the other hand, measuring only the formal level of education may overestimate the level of human capital because it has increased a lot over time. Therefore, it is assumed that net effect of all these factors equals zero, making the change in human capital affected solely by the level of formal schooling and thereby following what is the most common way of measuring it. Further, the level of formal schooling is easily measured and is the most obvious variable affecting the level of human capital. What concerns us here is the change in the level of human capital, so if the net effects from the discussion above can be assumed to have been constant they have not affected the change in human capital. Then, the absolute values are not so important. Yet, they are indexed in order to clearly see these changes. The indices must be seen as approximations to real changes in human capital, no absolute truths. Below it is described how the change in human capital in each sector is constructed from educational statistics from Barro-Lee and SCB. Figure 4.5 shows the results.

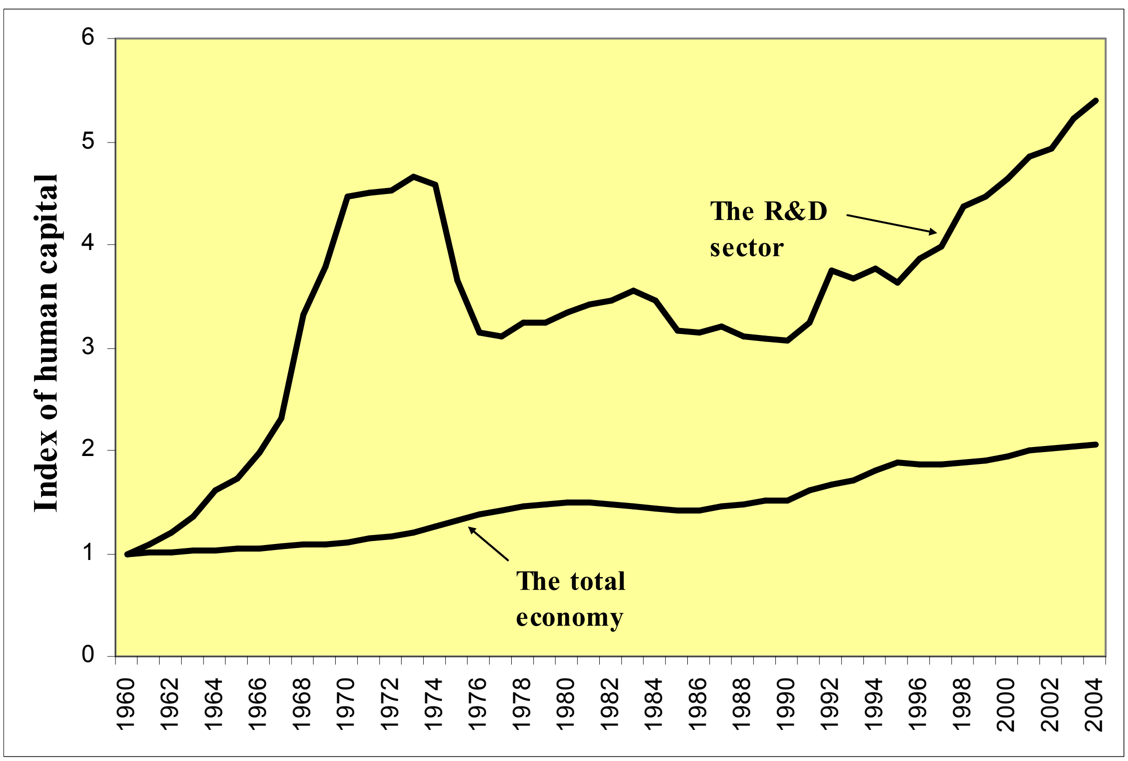

Figure 4.5: Indices of human capital in the R&D sector and the total economy.[40]

[40] Barro-Lee and SCB

4.4.2 The R&D sector

Human capital in the R&D sector is first and foremost affected by the amount of higher education. R&D personal is then assumed to have a university degree of some level, from basic to advanced levels. Human capital in the R&D sector is therefore constructed by the change in the amount university degrees, with a weighted average between different levels. The weights are equal for basic and advanced degrees. Of course, the basic degrees are much more in numbers, but on the other hand, the advanced degrees can be assumed to have a larger impact on the R&D sector. Human capital in the R&D sector is also adjusted for changes in both the labor force and the share of the labor force working in that sector. According to this discussion, human capital in the R&D sector has increased for three reasons; the increase in university degrees, labor force and the share of the labor force working in the R&D sector, with the latter two relatively small compared to the first.

Two things are worth noting from figure 4.5. The large drop in the index in the middle of the 1970´s may look odd, but it is a result of the way the calculations are made. As noted, they first and foremost take into account the change in university degrees and there were large drops in these during the period. But in reality, there is no reason to expect the level of human capital to decrease so much in just a few years; people do not just forget what they have learnt in such a short period of time. Another thing to notice from the diagram is the huge increase in human capital during the period, a roughly five-fold increase. This is also because the calculations are mostly based on the numbers of university degrees. But not everyone with a university degree is working in the R&D sector. The constructed index of human capital should then be seen as what is potentially available for the R&D sector, not what actually has happened there. As was discussed in the beginning of this chapter, the way these calculations have been made is just assumptions, no absolute truths. Then, this is one possible approximation to the change in human capital, but others are certainly possible.

4.4.3 The total economy

In the total economy, the level of human capital is assumed to be affected by the general level of schooling, both higher and lower, and by growth in the total population. The calculations are based on the following assumed weights:

	Weight
Average years of schooling	**0,5**
Second level schooling	**0,2**
Higher level schooling	**0,2**
Population growth	**0,1**

Then, it is assumed that average years of schooling is the most important factor to human capital in the total economy and that the other factors are less important. Further, it is assumed that new workers leaving school are mixed with the existing labor force which has a lower level of schooling. This is not true for the R&D sector in the same way. There, it can be assumed that almost everyone is well-educated. New jobs created there will also be taken by well-educated workers, so the change in university degrees is a good approximation to that index. Because this is not the case in the total economy, its index of human capital is lowered by 20 percent each year, which is also just an assumption. The result from these calculations is also presented in figure 4.5.

In this chapter empirical facts have been presented. They are the key variables in the theoretical models. Although measurement problems certainly exist, these facts are supposed to represent how the economy actually has evolved. The following chapter will use them and analyze how they compare with the models´ results. These results can perhaps give a clue of whether R&D efforts in Sweden are optimal or not.

5. Comparison with the models

This chapter compares the empirical facts in chapter 4 with the growth models presented in chapter 3. In order to do this, the economy will be analyzed around its equilibrium which is represented by table 4.2. According to the previous discussion this analysis will be highly speculative of because the very complex nature of R&D and lack of relevant data. Therefore, this chapter too will make many assumptions about the economy and see what their implications are. The assumptions are described throughout the chapter. The analysis will be done in two steps. Because knowledge production is affected by other factors than the R&D sector, section 5.1 will use the general function for knowledge production to test this issue. It gives an implication of the most important factors to knowledge production and where the economy stands relative to its equilibrium. Section 5.2 looks at implications on the optimal level of R&D efforts by using the Romer model. Combining the results from both sections could give some overall view of whether the question in the introduction was justified.

5.1 Knowledge production

The model of knowledge production presented in section 3.1 aims to describe how the physical capital stock and the level of technology change on the balanced growth path. This will be tested empirically by specifying an econometric model. Then, these dynamics are transformed into a diagram that shows where the economy stands in relation to its equilibrium. Some modifications of the model must be done. First, population growth in the model means population growth on a global scale. The idea is that, the more people there are, the more people there are to make discoveries. This would probably have a very small impact looking at Sweden separately because the population growth is relatively low, but also because Sweden's population represents only a tiny proportion of the world's population. Therefore, population growth will be replaced by growth in human capital which hopefully will make more sense. The reason for this is that when workers have more education they can be assumed to be "better equipped" to make new discoveries. The original idea is then translated into this modified model which is looking at a single economy in isolation. But since the level of productivity outside Sweden will inevitably affect productivity growth inside Sweden, the model will also be tested by taking this into account. Because of this, two different groups of series will be used, one for Sweden in isolation which will be called regression 1, and one in which world productivity is considered, called regression 2. Because the time period considered in the latter case is shorter, the two series are not directly comparable and need to be separated. However, the focus is on the first regression.

5.1.1 The econometric model

By specifying an econometric model, the empirical facts can be used to find the most important factors to knowledge production. The general characteristics of knowledge production can also be investigated. In order to get the econometric model as realistic as possible it must reflect the nature that characterizes R&D activities. Research typically takes long time; it may take several years to complete a research project and then it takes time to introduce a new technology in the production process and get the market to accept it.[41] Therefore, R&D activities undertaken this year will affect growth rates in the future, or equivalently, high growth rates this year is a result of large R&D activities in the past. Because of this, it seems quite meaningless to relate R&D activities a particular year to growth rates in the same year. It is more adequate to introduce a lag structure that relates growth rates to past changes in the independent variables. Also, getting information about the lag structure is important because future benefits from R&D can be evaluated in present value terms. However, it is quite difficult to get reliable results because the time period involved is usually long.[42] Furthermore, information about the lag structure will show how fast the relative response is when changing some of the independent variables. Because of this nature of R&D, a dynamic econometric model will be used; a so called second degree polynomial distributed lag model. This model relates growth rates in a particular year to changes in the independent variables in previous years. A second degree polynomial function means that the effects on growth rates can be described by an ordinary second degree function, that is, by a parable. In such a function the effect

[41] Griliches (1998), p. 27
[42] Balcombe, Bailey and Fraser (2005), p. 49-50

increases geometrically, reaching a maximum after some years. It then declines geometrically and dies out. This can be assumed to be a good approximation of the actual R&D process. In the first years, there will be only a modest effect from R&D activities because the innovation has not yet reached its full potential. After the effect from the innovation has reached its maximum it will be replaced by new and better technology, and therefore, the effect will decrease and eventually die out. Equation (3.8) can then be transformed into an econometric model by adding an error term $e(t)$, introduce new coefficients and using a vector notation according to the function

$$\frac{\dot{g}_A(t)}{g_A(t)} = \beta_{Ki}\vec{g}_K + \beta_{Si}\vec{g}_S + \beta_{Ai}\vec{g}_A + e(t), \tag{5.1}$$

where $\vec{g}_K$, $\vec{g}_S$ and $\vec{g}_A$ are vectors of growth rates in the past:

$$\begin{aligned} \vec{g}_K &= g_{Kt} + g_{Kt-1} + \ldots + g_{Kt-n} \\ \vec{g}_S &= g_{St} + g_{St-1} + \ldots + g_{St-n} \\ \vec{g}_A &= g_{At} + g_{At-1} + \ldots + g_{At-n} \end{aligned} \tag{5.2}$$

The vector notation in (5.2) describes the fact that productivity growth rates are affected by what has happened in the past, or that research takes time and will not affect the economy until some years later. Following the notation of the parameters in chapter 3, $\beta_{Ki} = \beta$, $\beta_{Si} = \omega$ and $\beta_{Ai} = \theta - 1$. Also, as discussed above, g_S here means growth rates of human capital in the total economy instead of the population growth rate. N stands for the lag length which is the amount of years assumed that changes in the independent variables will have an effect on knowledge production. In order to get a distributed lag model, the coefficients are transformed according to the second degree polynomial function

$$\beta_{Xi} = \mu_{X0} + \mu_{X1}\left(i - \frac{N}{2}\right) + \mu_{X2}\left(i - \frac{N}{2}\right)^2, \tag{5.3}$$

where X indicates the independent variable and i indicates the year considered. μ is the variable that will be estimated in this model. Assuming the coefficients have the form in (5.3) means that the effects on knowledge production have the characteristics that was described above. However, the transformation (5.3) may be done in other ways, but it is how it is done by EViews.[43]

5.1.2 Econometric problems

This paper mainly deals with time series variables. Such variables have some special characteristics that have to be taken into account when applying econometric methods on them. Time series data often move in a particular direction, that is, they follow a random walk. The variables underlying the growth rates shown in figure 4.3 typically grow over time. For example, GDP grows over time and does not show any tendency to return to lower levels. Such variables do not have a constant mean and are therefore said to be nonstationary which means that they are trended.[44] If more than one nonstationary variable are related to each other via ordinary least squares, the result can be spurious. This means that, because they are trended, it will look like there is a statistical relationship between them even if there is none in reality. In such a case, the estimates and R^2-values are misleading or meaningless.[45] However, there is a special case that should be considered. If pairs of nonstationary variables move together in a systematic way, then there is a long run relationship between them and they are said to be cointegrated. This means that the variables can be estimated via ordinary least squares without causing spurious results. A cointegration relationship can give valuable information about the relationship between the variables. A formal test on stationarity is carried out via a unit root test in EViews, a so called Dickey-Fuller test. The null hypothesis in this test is that the variable has a unit root which implies nonstationarity. If a variable *X* has a unit root it follows a random walk which can be described by

$$X_t = X_{t-1} + \upsilon_t \tag{5.4}$$

where υ_t is an error term that is uncorrelated with prior periods. Equation (5.4) illustrates that the effect from year *t-1* is fully carried over to year *t* and does not diminish. This is because the coefficient before X_{t-1} is equal to 1, hence the name unit root. A cointegration test is carried out in the same way, but instead of testing whether a single

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[43] Reiman and Hill (2001), p. 148
[44] Hill, Griffiths and Judge (2001), p. 335-336
[45] Kennedy (2003), p. 319

variable has a unit root, it tests whether the difference between two nonstationary variables that have been related via ordinary least squares has a unit root. If this is not the case, a cointegration relationship exists.[46]

According to the discussion above, nonstationary time series can cause some problems. However, nonstaionary variables can be made stationary by differencing and thereby avoiding these problems.[47] This is what is done in figure 4.3; the diagrams show the growth rates of the underlying series and by visual inspection of them it can be seen that there are no clear trends in any direction and they are therefore stationary. But as described above, this can also be tested more formally in EViews. But even if variables are stationary there can still be a problem of multicollinearity. Because they may follow similar trends over time, it is difficult to separate their individual effects.[48] But by imposing the lag structure in equation (5.3), the problem with multicollinearity will be reduced.[49] Another relevant problem with estimating these time series is the problem of causality; it is difficult to know if past R&D efforts have led to high economic growth or if high economic growth rates in the past have led to large R&D efforts.[50] According to the previous discussion it is certainly true that R&D is positive to growth rates. But high growth rates will result in higher incomes, making it possible to spend more on R&D. Therefore, both assertions are likely to be true. Separating these effects will then be very difficult.

5.1.3 Results

First, the issues of stationarity and cointegration will be checked out. If a cointegration relationship can be found, it can be used to find out more about the nature of knowledge production. In this case, the undifferentiated (original) data series will be used. The EViews output of the Dickey-Fuller unit root test on real GDP, physical capital and productivity is presented in table 5.1. Comparing the ADF statistics with the critical values it can be seen that the null hypothesis of a unit root cannot be rejected for any of

[46] Hill, Griffiths and Judge (2001), p. 343-347
[47] Ibid, p. 325-327
[48] Griliches (1998), p. 33
[49] Hill, Griffiths and Judge (2001), p. 323
[50] Griliches (1998), p. 34

the variables. The conclusion is therefore that all of these variables are nonstationary. A similar test for the data series on productivity outside Sweden gives the same result. Then, as would be expected from these types of data, there is statistical evidence that they follow a clear trend over time.

	ADF test statistic
Real GDP	**0.865301**
Physical capital	**2.749854**
Human capital	**0.993795**
Productivity	**0.746430**

	MacKinnon critical values for rejection of the null hypothesis
1 %	**-3.5850**
5 %	**-2.9286**
10 %	**-2.6021**

Table 5.1: Dickey-Fuller test of stationarity and critical values for rejection of the null hypothesis of a unit root.

Using the same approach to test for cointegration relationships, the variables have first been related to each other via ordinary least squares. Since there are many independent variables there are many possible relationships as well. The ADF statstistics for the differences between the variables are shown in table 5.2.

	ADF test statistic
Real GDP – Physical capital	**-1.492653**
Real GDP – Human capital	**-1.779763**
Real GDP - Productivity	**-1.943390**

Table 5.2: Cointegration test for pair of variables.

The conclusion from these results is once again that the null hypothesis of a unit root cannot be rejected for any of the pairs. The residuals are therefore nonstationary and there is no statistical evidence of any cointegration relationships. Then, because the variables are not moving together in any systematic way, not much can be learnt by running regressions on these undifferentiated series. However, the econometric model described by equations (5.1)-(5.3) uses differentiated values (the growth rates) and therefore, the problem with spurious results is avoided. This econometric model will now be run. First, the issue of multicollinearity will be checked out. This is done by looking at the correlations coefficients between the independent variables. Table 5.3 shows these coefficients between the independent variables for regression 1 and table 5.4 for regression 2.

	Productivity	Physical capital	Human capital
Productivity	**1**	**0.40**	**-0.04**
Physical capital	**0.40**	**1**	**0.19**
Human capital	**-0.04**	**0.19**	**1**

Table 5.3: Correlations between the independent variables for regression 1.

	World productivity	Physical capital	Human capital
World productivity	**1**	**0.56**	**0.14**
Physical capital	**0.56**	**1**	**0.43**
Human capital	**0.14**	**0.43**	**1**

Table 5.4: Correlations between the independent variables for regression 2.

These correlations are not too serious. A suggestion is that if the correlation coefficients are higher than 0.8 in absolute terms, then it is almost impossible to separate the effects from each variable.[51] Most of the coefficients in this sample are much lower but it should be remembered that the problem of multicollinearity still exists.

In order to estimate the coefficients in the econometric model (5.1), the dependent variable is calculated as the growth rate of the growth rate of productivity. However, this variable will vary much from year to year. The variables affecting productivity (real GDP and hours worked) can change quite fast if, for example, there is a recession in one year. Then, the percentage change in the productivity growth rate will naturally be very large for that year. Since we are not interested in such short-run fluctuations, it seems wisely to try to eliminate these. Therefore, a three-year trend value will be created for the dependent variable. The trend value is calculated by taking the mean of that year's value and the two surrounding years´ values. This should be no problem to the estimation process because, as previously discussed, there is little relevance of relating the

[51] Hill, Griffiths and Judge (2001), p. 190

dependent and independent variables for an individual year. However, it will sharply reduce volatility. Using longer trends years could reduce volatility more, but there is a drawback with this as well; it reduces the length of time that can be included in the regression. Of course, it is better to have a long period to estimate than a short one. There is also a trade off when choosing the appropriate lag length. A long lag length is good because R&D effects probably take long time to work out, but it also reduces the regression sample. A reasonable number is 4-19 years and that is what is mostly used in these kinds of analyses.[52] The lag length is in this case assumed to be 8 years. The result from regression 1 described by equations (5.1)-(5.3) is shown in table 5.5.

	Coefficient	Std. error	t-statistic	p-value
Intercept	4.737932	2.841870	1.667188	0.1075
μ_{K0}	23.35041	32.27177	0.723555	0.4758
μ_{K1}	-40.98940	10.98946	-3.729883	0.0009
μ_{K2}	-2.731401	4.737830	-0.576509	0.5692
μ_{S0}	15.56984	10.33368	1.506708	0.1439
μ_{S1}	6.978837	2.915129	2.394006	0.0242
μ_{S2}	-2.789990	1.635349	-1.706052	0.0999
μ_{A0}	1.907763	15.20240	0.125491	0.9011
μ_{A1}	0.612904	4.693653	0.130581	0.8971
μ_{A2}	-2.408811	1.972661	-1.221098	0.2330

Table 5.5: The EViews regression 1 output of the distributed lag model. Sample 1962-2004.

As can be seen by the p-values in the diagram, the results are not very significant. This illustrates the inexact nature and the difficulties of measuring relationships between the variables. But the hope is nevertheless that some general pattern can be found. Substituting the estimates of μ into equation (5.3) gives the values for the coefficients for each year. These coefficients are then shown in figure 5.1 where they are measured on the y-axis. They can then be interpreted as the effect they have on the dependent variable at every point in time. The x-axis shows the time of the lag length, in this case 8 years.

[52] Balcombe, Bailey and Fraser (2005), p. 51

Then the lines give information about the lag distribution of the effect of each variable and the magnitudes involved. The corresponding coefficients for regression 2 are presented in figure 5.2. Also, the sums of the coefficient values are shown in table 5.6.

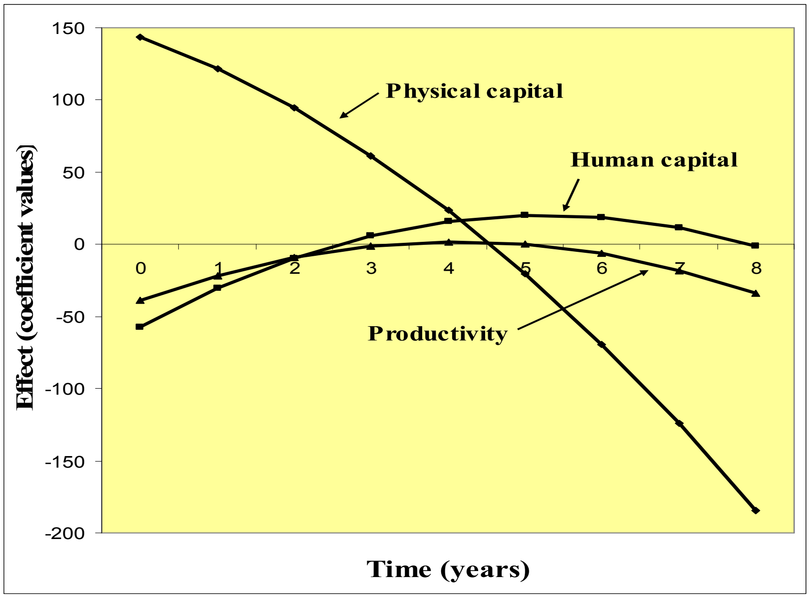

Figure 5.1: Coefficient distribution for regression 1.

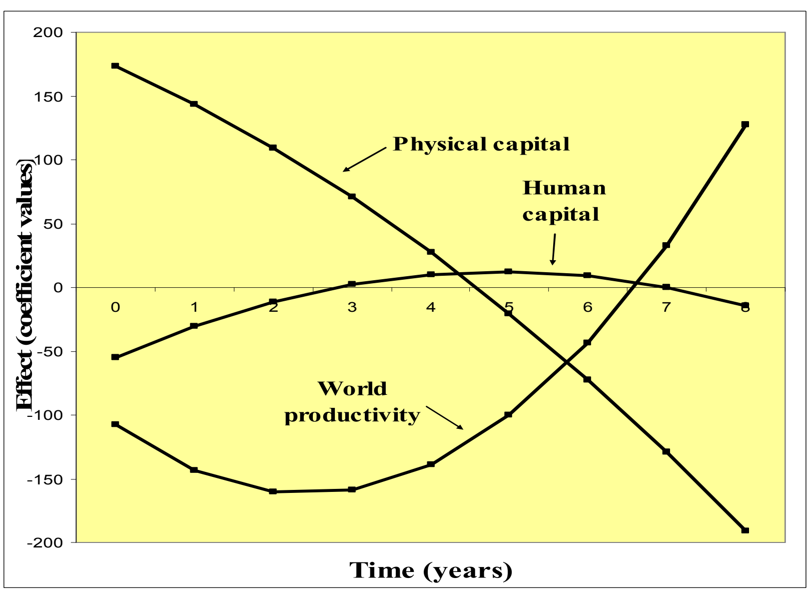

Figure 5.2: Coefficient distribution for regression 2.

	Sum of lags regression 1	Sum of lags regression 2
Physical capital	**46,3**	**112,0**
Human capital	**-27,3**	**-78,6**
Productivity	**-127,4**	**-693,0**

Table 5.6: Sum of lags of the coefficient values in the regressions.

Figure 5.1 and 5.2 must be evaluated with care. The absolute values of the coefficients are certainly not correct, they are too large. One obvious reason for this is what was discussed above; the large volatility in the dependent variable. Even though it was reduced by creating a trend value it is still relatively large. Thus, the effects from short run fluctuations in the economy cannot be totally eliminated, the time periods considered are too short. Further, if there is a boom, productivity growth is typically high. But eventually, when the boom is over, productivity growth must decrease, causing the growth rate of the productivity growth rate (the dependent variable) to decrease as well. Therefore, there is a risk of interdependence between these two variables that results in low values of the productivity coefficient. However, the results must be evaluated by returning to the original production function for knowledge, equation (3.4)

$$g_A(t) = \frac{\dot{A}(t)}{A(t)} = c_A K(t)^{\beta} L(t)^{\omega} A(t)^{\theta - 1}, \tag{5.5}$$

and by evaluating the relative values of the coefficients and the general features of the results. What is clear from figure 5.1 and table 5.6 is that physical capital accounts for the largest impact on knowledge production, but also the fastest impact. This effect comes instantaneously and then declines over time. This effect can probably be related to learning-by-doing. In terms of equation (5.5), this says that accumulation of physical capital is the most important factor to technological change. The effect from human capital is not only smaller; it also takes longer time. But educate people takes many years, so it is possible that this effect would differ if longer time periods were considered. The effects from physical and human capital are similar in both regressions. The negative values on productivity are in terms of equation (5.5) an indication of diminishing marginal returns in production of new knowledge. If θ is negative, then it becomes more difficult to come up with new ideas when A is high.[53] This seems reasonable; all variables in equation (5.5) have increased over time, but despite of this, productivity growth rates have not increased. This means that in order to keep productivity growth rates at even constant rates, the share of total resources devoted to R&D must be increasing. But obviously, this share cannot increase forever and even a more moderate increase would take resources away from the goods producing sector. This implies that productivity growth rates will eventually decrease which in turn leads to lower GDP growth rates as well. But according to figure 5.2 the results differ in the two regressions. World productivity eventually has a positive effect on the dependent variable, suggesting that the technological level in the world has a positive effect on knowledge production inside Sweden, but with retardation.

To see where the economy stands relative to its equilibrium and how it has evolved over time, a dynamic diagram can be used. The equilibrium point is given by the values on the balanced growth path in table 4.2. The results above suggest that in absolute terms, the effect from physical capital is roughly twice as large as from human capital, that is, $\beta = 2\omega$. Also, the effect from productivity, θ, is negative, say -0.5. The geometric mean for growth in human capital is calculated to 1.66 percent annually. In equilibrium, the growth rates of the growth rates in equations (3.8) and (3.9) must equal zero. These two equations can then be combined to find a condition for equilibrium. By using this fact and the suggested results form the regression, the equilibrium is given by

$$g_A = \frac{\beta + \omega}{1 - (\theta + \beta)} g_S \Rightarrow 0.0268 = \frac{\beta + 2\beta}{1 - \left((-0.5) + \beta\right)} 0.0166 \Rightarrow \beta = 0.53 \Rightarrow \omega = 0.26 \quad (5.6)$$

The dynamic diagram is then shown in figure 5.3.

[53] Romer, D. (2001), p. 100-101

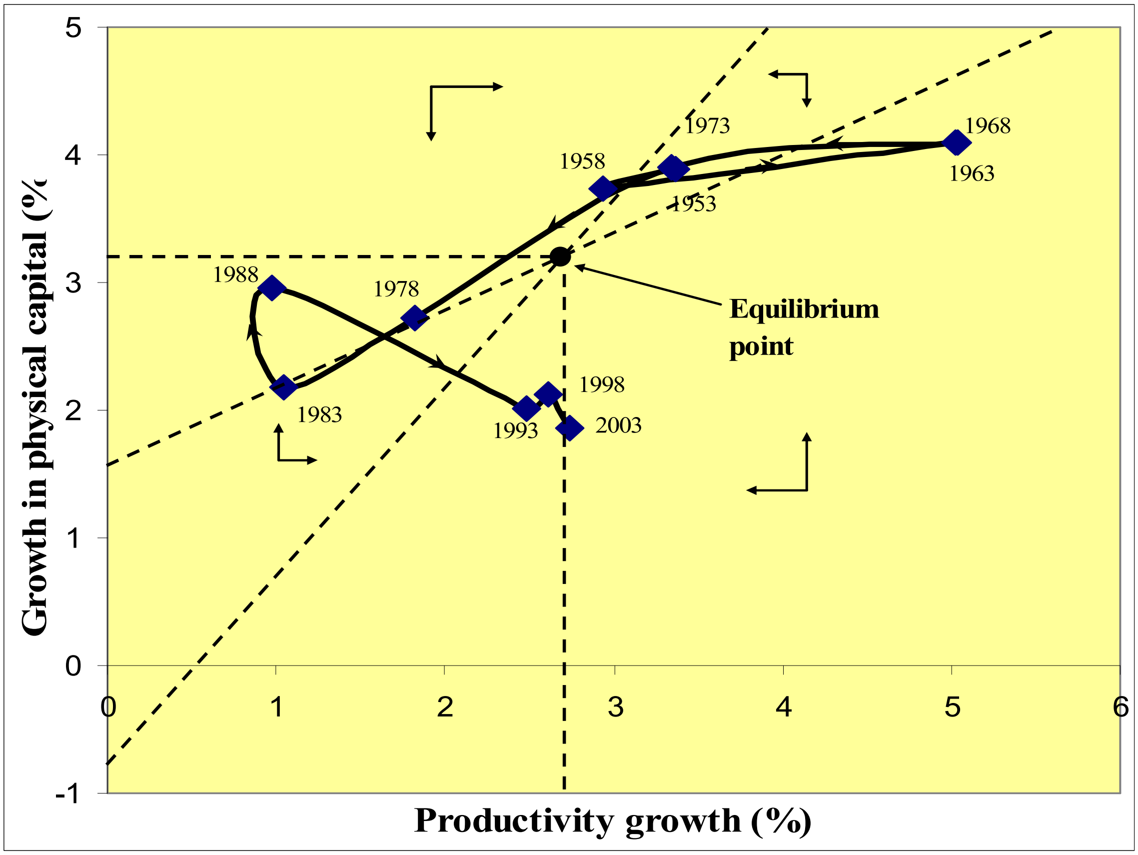

Figure 5.3: The evolution of the economy relative to its equilibrium.

In this diagram, the perpendicular broken lines mark the equilibrium values of physical capital and productivity. The other two broken lines mark where the changes in growth rates of physical capital and productivity are zero. From equations (3.8) and (3.9), they intercept at n (g_S in this case) and $-\omega n/\beta$ ($-\omega S/\beta$) respectively. The points for each year in the figure are calculated as the mean of the growth rates in the five year period surrounding that year. The figure shows how the economy has moved around the equilibrium point. The productivity growth rate is close to its equilibrium, but the growth rate of physical capital is inferior compared to the balanced growth path. According to the diagram, the economy now stands in the area where it should be moving up to the left, that is higher g_K and lower g_A. A higher growth rate of physical capital means, according to the regression above, an immediate positive effect on knowledge production. But at the same time, the diagram suggests a lower or unchanged productivity growth rate, so the overall effect is ambiguous. However, it is not certain that the equilibrium point is fixed over time. When fundamentals in the economy change, it is likely that the equilibrium point changes as well. Then it is not for sure that the equilibrium point shown in the diagram is the true point, but it is what is assumed here.

5.2 The socially optimal level of R&D

Last section determined the most important factors to knowledge production and where the economy stands relative to its equilibrium. This section analyzes the behavior of the economy in steady state and takes advantage of the Romer model in section 3.2 to see what the implications are for the socially optimal level of R&D. The optimal level of R&D is analyzed both in terms of human capital and share of GDP that is devoted to R&D. But in order to do this, first some parameters will be estimated and then the research success parameter will be determined.

5.2.1 Estimation of parameters

In the production function for the total economy in the Romer model, equation (3.10), output is given by

$$Y = S_Y^{\alpha} L_0^{\beta} \int_0^A x(i)^{1-\alpha-\beta} \, di \, . \tag{5.7}$$

In this function, L_0 represents total labor and S_Y represents human capital in the total labor force. Therefore, L_0 can be seen as labor with no education, which is then multiplied by the index of human capital, S_Y. $L_0 S_Y$ is referred to the effective labor force. Then, β and α represent the share of each variable in the production function, that is, how much it "is worth" in the production of goods. Taking a standard microeconomic assumption that the marginal product for each input should be equal to its price it can be assumed that workers are paid their marginal product.[54] Wage differences between high- and low-educated workers can therefore be used to estimate β and α. Table 5.7 shows these differences for various levels of education.

[54] Varian (1992), p. 26

Level of schooling	Wage per month (SEK)
Primary school, less than 9 years	20 450
Primary school, at least 9 years	20 900
High school, less than 2 years	21 900
High school, 3 years	22 200
University, less than 3 years	26 200
University, at least 3 years	30 700
Advanced level	39 250

Table 5.7: Wages for different levels of schooling 2005.[55]

Treating the first three groups in table 5.7 as low-educated and the other as high-educated we have only two groups, the first representing L_0 and the second $S_Y L_0$. Taking the mean of the wages in both groups, the ratio between these is approximately 1.4. It is often assumed that the share of physical capital in such production functions is around one-third.[56] This in turn means that $\beta + \alpha = 2/3$. Then, if the ratio between the wages should fit, $\beta = (2/3)(1.4/(1+1.4)) \approx 0.4 \Rightarrow \alpha = 0.3$. That is, the share for high-educated workers is 0.4, for low-educated workers 0.3 and for physical capital 0.33.

5.2.2 The research success parameter

The research success parameter, σ, is a measure of how productive knowledge production is. According to the steady state condition for the growth rate, equation (3.18)

$$\frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \frac{\dot{C}}{C} = \frac{\dot{A}}{A} = \frac{\sigma(\alpha+\beta)S_0 - \alpha\rho}{\alpha\varphi+\beta}, \tag{5.8}$$

the growth rate is an increasing function in σ. But the growth rate is also an increasing function in human capital in the total economy, $S_0 = S_A + S_Y$. According to section 4.4, this variable has been steadily increasing. Since the growth rates according to figure 4.3 do not show any particular trend over time and assuming that the other parameters are constant, the research success parameter must have decreased. By solving for σ in (5.8) and using the mean of the growth rates for each year, it can be seen how the research success parameter has changed over time. This is shown in figure 5.4.

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[55] SCB, http://www.scb.se/templates/tableOrChart____149081.asp (2006-12-20)
[56] Romer, D. (2001), p. 23

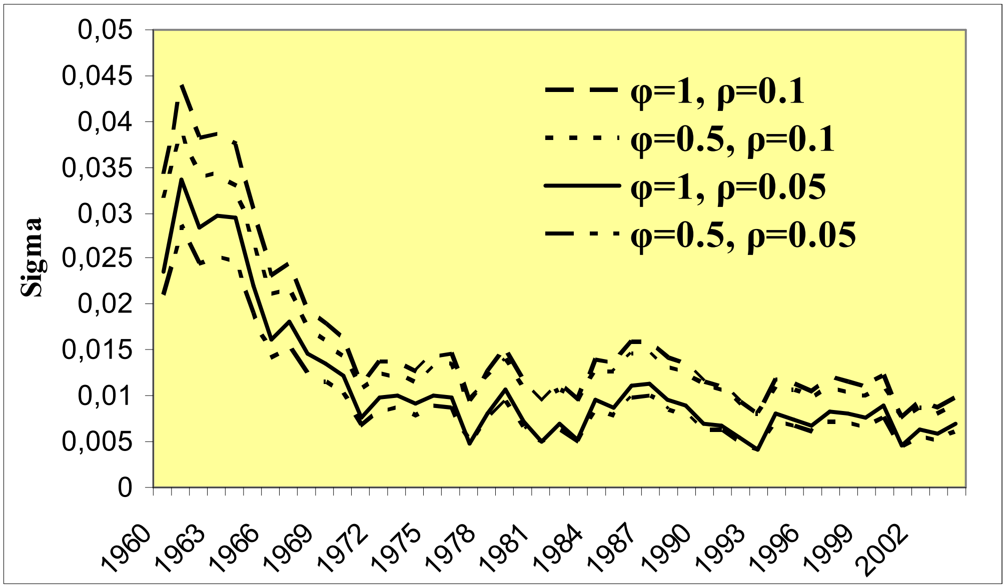

Figure 5.4: The research success parameter.

The figure shows σ with some different values on φ and ρ, but in each case they are assumed to be constant over the period. The values are suggested by David Romer in a similar problem on economic growth.[57] In this case then, some other values on these parameters are also tested to get a feeling of the differences in the results. The two remaining parameters, α and β, are set to 0.3 and 0.4 respectively according to the previous section. The location of the curves is somewhat different for different values on φ and ρ, but the general pattern is the same. As can be seen, the research success parameter has steadily decreased over time, that is, the productivity of R&D activities has decreased. Put in another way, it can be said that each worker comes up whit fewer new ideas now than they did in the past. There are many possible explanations to this. First, it was suggested in section 5.1.3 that θ is negative which means that it becomes more and more difficult to come up with new ideas the higher the technological level is. This is equivalent to saying that the research success parameter has decreased when the level of technology has increased over time. Another possible explanation that has been suggested is that it is the amount of R&D activities per line of business that matters, not the overall amount of R&D activities. When the economy grows it is likely to become more

[57] Romer, D. (2001), p. 68

differentiated with many different kinds of products.[58] Then, it is possible that same sorts of R&D activities are made many times, but in different industries. Also, competing firms that develop similar products are likely to undertake same kinds of R&D activities. As was discussed in section 4.1.2, most of the R&D activities take place in the business sector which makes this explanation meaningful. When this is the case, decisions on what research project to invest in are made by each particular firm. Then, there is no social planner who coordinates the activities and the R&D activities are not efficient from a social perspective.

5.2.3 Conditions of optimality

The objective of the Romer model is to maximize utility from aggregate consumption which in turn will maximize welfare of the society. This maximization technique is called optimal control theory because it is assumed that there are variables that can be controlled; the control variables. By choosing the optimal path for the control variables the objective of the maximization problem will be met. In this case the control variables are technology and physical capital and the maximization problem is described by (3.16). The solution of this problem is given as the level of human capital in the R&D sector in steady state, equation (3.17),

$$S_A = \frac{\sigma(\alpha+\beta)S_0 - \alpha\rho}{\sigma(\alpha\varphi+\beta)}. \tag{5.9}$$

Equation (5.9) builds on certain conditions that result from the solution of maximization problem (3.16). A part of the solution and what also precedes equaiton (5.9) is the condition

$$-\varphi S_A \sigma = \rho - \sigma\left(S_0 \frac{\alpha+\beta}{\alpha} - S_A \frac{\beta}{\alpha}\right), \tag{5.10}$$

where the left hand side is derived from the marginal benefit condition for physical capital and the right hand side from the marginal benefit condition for technology. The derivations of (5.9) and (5.10) are not easily explained but are shown in appendix 1. Because these two equations build on maximization principles they can be seen as optimal conditions in steady state. Equation (5.9) can be seen as the optimal time path of

[58] Romer, D. (2001), p. 114

human capital in the R&D sector and equation (5.10) a condition of the optimal path of distribution between human capital in the total economy and the R&D sector. These conditions can then be compared with actual values.

5.2.4 Results

The comparison between actual and optimal values will be made by assuming that the research success parameter varies over time as was described in section 5.2.1. Also, the indices on human capital presented in section 4.4 are assumed to describe the actual values of human capital. As was discussed there, the absolute values on human capital have no meaning, since they are just given an arbitrary number (in this case 1 in 1960). However, because the calculations on both the actual values and the optimal values are based on the same indices on human capital, they are comparable. By substituting the values on σ, the sum of the human capital indices and the remaining parameters in equation (5.9), the optimal path of S_A can be found. This path and the actual indices are shown in figure 5.5 fore some different values on φ and ρ.

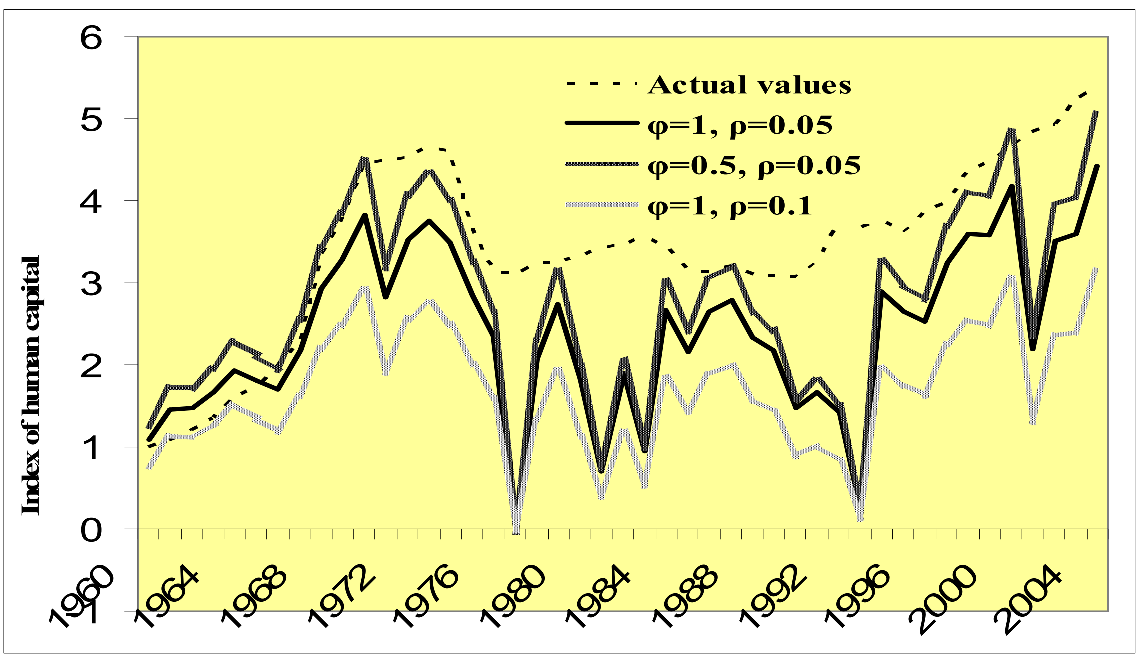

Figure 5.5: Actual and optimal paths of human capital in the R&D sector.

As can be seen, the optimal values are lower than the actual ones, implying that the level of high educated workers is too high. However, the optimal levels are much more volatile than the actual values which depend on the stochastic nature of the economy. It seems unreasonable that it is optimal to follow such a path, but the overall trend should be considered instead. Since the construction of human capital indices considered both the amount of students and the length of education, it is both possible that there are too many high educated workers, or that workers have too long educations, or both. Figure 5.5 does not tell which of these options are most likely, only that the overall level is too high. To search for the optimal level of human capital in the R&D sector, equation (5.10) will be used. In order to be optimal, both sides of this equation must be equal. But since the variables vary from year to year, different levels of human capital in the R&D sector will be tested. That is, because the level of S_A is proved to be too high, different values on the level of S_A is tested by asking "what if?" the level of S_A would have been X percent lower each year during the period. Then, by showing both sides of the equation as a curve, it can be seen for what level on S_A the two curves are equal looking at the period as a whole, or for what level the two curves fit best together. According to figure 5.5, the case where $\varphi = 1$ and $\rho = 0.05$ is the middle curve of the three cases, so this case can be considered as the most likely one and will therefore be used here. The curves of optimality, building on equation (5.10), are shown in figure 5.6.

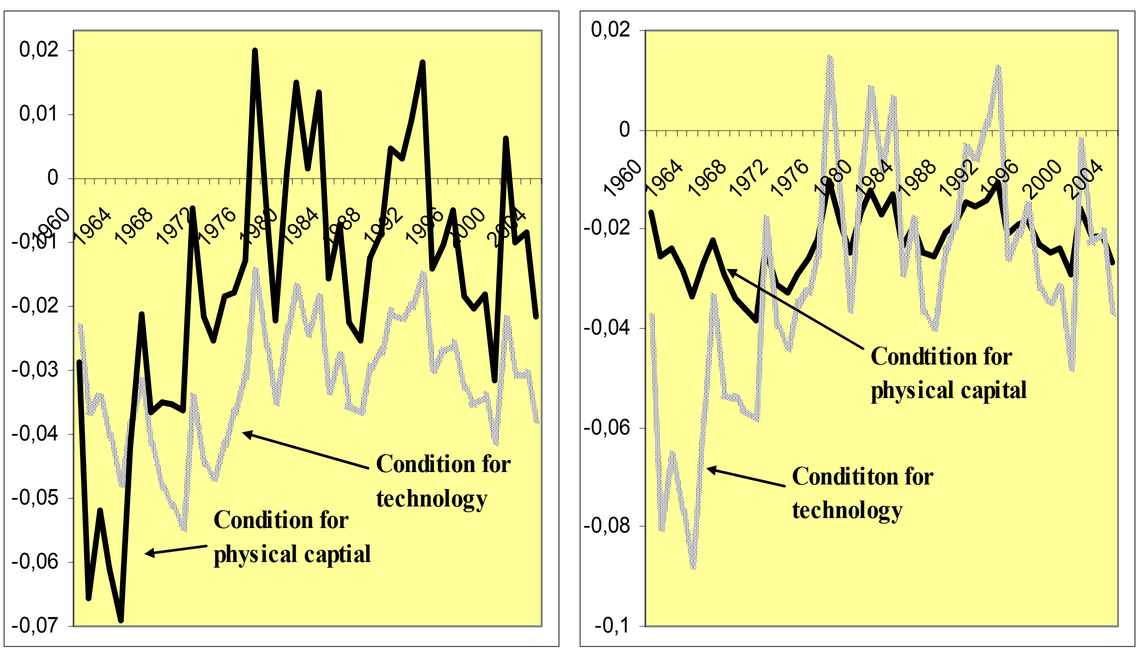

Figure 5.6: Conditions for optimality. The left figure: actual values. The right figure: values if human capital would have been 30% less each year.

The left part of figure 5.6 shows the conditions in equation (5.10) with actual values. As can be seen, the curve for physical capital is mostly above the curve for technology, implying that the level of human capital in the R&D sector is not optimal. Then, different values on the level of S_A have been tested. By visual inspection, the two conditions are roughly equal, seeing the period as a whole, when the level of S_A is reduced by 30 percent each year. This is equivalent to saying that the level of human capital in the R&D sector is a good 40 percent too high. This is shown in the right part of figure 5.6.

The same calculations will now be made on the share of resources devoted to the R&D sector. Total resources are here simply assumed to be GDP and the share of GDP that is devoted to the R&D sector is presented in section 4.3. In section 3.2 it was noted that the production function for knowledge (3.13) in the Romer model is assumed to be proportional to the level of human capital in the R&D sector. But this function can be seen as a special case of the more general production function (3.14), where the level of human capital in the R&D sector is replaced by the share of GDP that is devoted to the R&D sector, a_Y. By setting the depreciation rate of technology, δ equal to zero, the production function for knowledge can be described by

$$\dot{A} = a_Y \sigma A . \tag{5.11}$$

The only difference between (5.11) and (3.13) is that S_A is replaced by a_Y. Therefore, equations (5.8), (5.9) and (5.10) can be used in the same way as for human capital by simply replacing S_A by a_Y. Furthermore, S_O must also be replaced by total resources in the economy, that is, GDP. Human capital in the preceding analysis was indices illustrating changes in human capital each year. The same approach will be made in this case. This means that, values on both the share of GDP devoted to the R&D sector and GDP are set to 1 the first year which in this case is 1984. Then, they are adjusted by the change in each year for each variable. These indices can then be used in the same way as the indices on human capital. The results from these calculations are shown in figure 5.7 and 5.8.

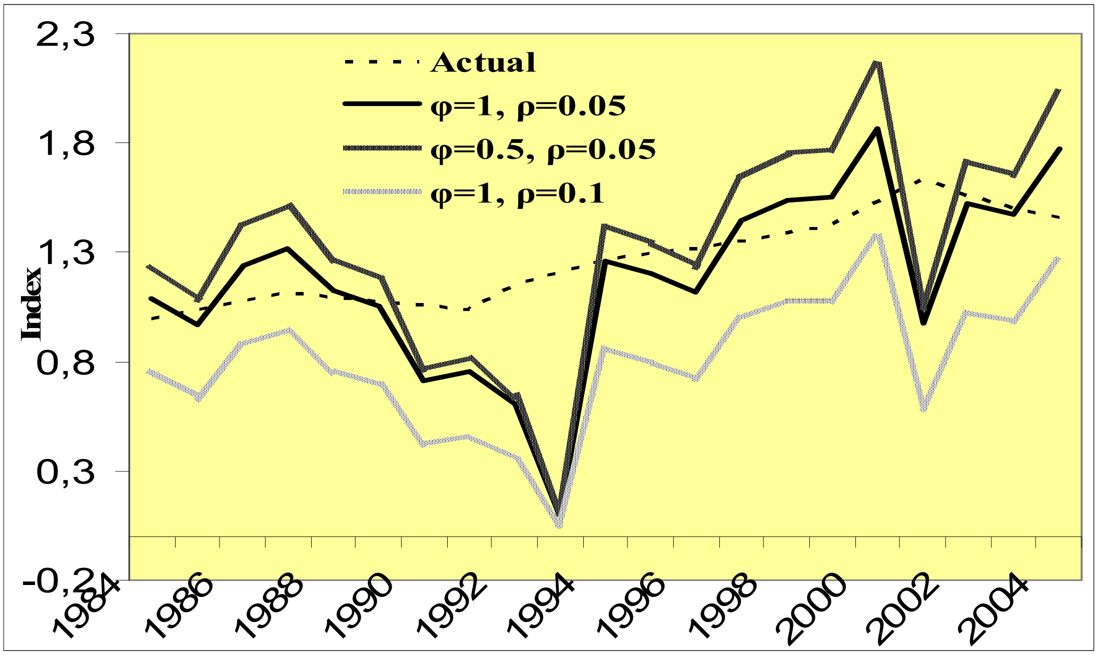

Figure 5.7: Actual and optimal paths of the share of GDP devoted to R&D.

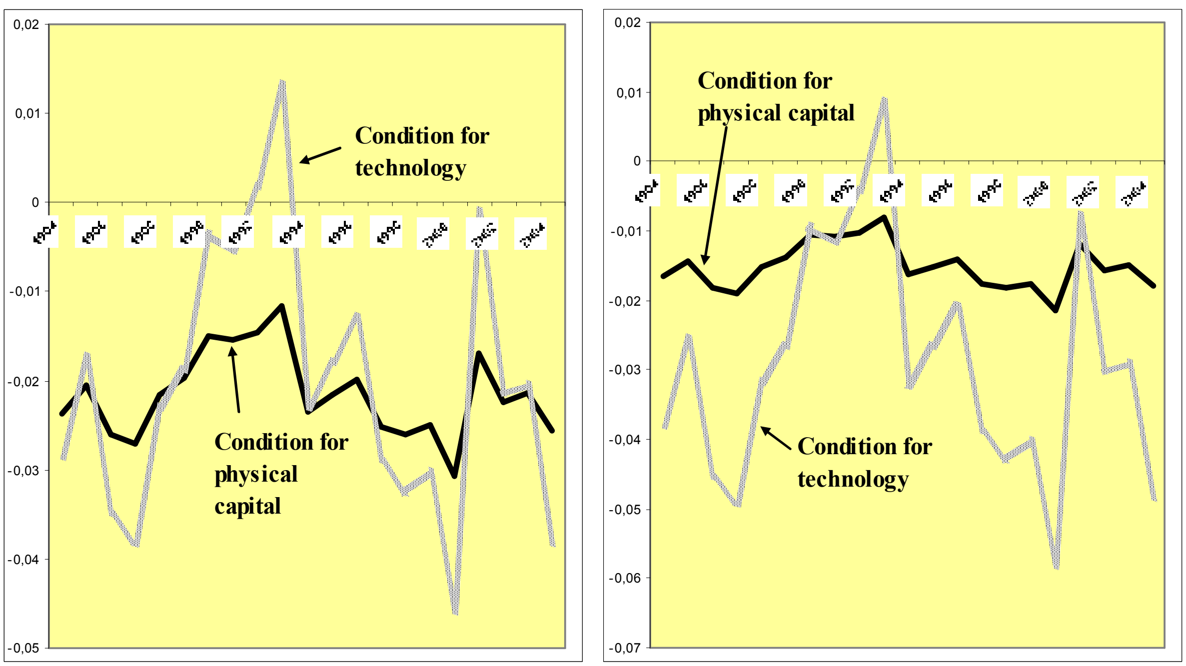

Figure 5.8: Conditions for optimality. The left figure: Actual values. The right figure: values if the share of GDP devoted to R&D would have been 30% less each year.

As can be seen in the diagrams, this case with the share of GDP devoted to R&D, the results are somewhat different than the case with human capital in the R&D sector. The actual shares of GDP that are devoted to R&D have been close to optimal. That is, even though Sweden is devoting most resources to R&D as a share of GDP, this analysis shows that they are not too large. In figure 5.8, the same calculation as in figure 5.6 is made; reducing the share of GDP devoted to R&D by 30 percent each year to see how the optimal conditions would change. In this case it would not be optimal, but it made here just for illustration and to be comparable to the case with human capital.

The main conclusion from this section is that the share of R&D devoted to R&D is optimal but the level of human capital in the R&D sector is higher than optimal. There is one interesting thing to note in connection with this conclusion. As was discussed in section 4.1.2, most of the aggregate expenditures on R&D are made by the business sector, not by the government. Of course, the aim of the firms is to optimize their private spending on R&D, but this analysis also shows that they are optimizing from a social perspective. On the other hand, the level of human capital is to a much larger extent affected by centralized political decisions which may be made with other objections than economic optimization. Then, there is a larger risk that the level of human capital ends up not being optimal, which according to this analysis is shown to be the case in Sweden.

In section 5.2.1 it was shown that the research success parameter has decreased since the 1960´s. Looking at only this fact implies that marginal benefit from R&D activities has decreased as well. Despite of this, R&D activities have increased over the same period and are still optimal. This may seem troubling. But it may indicate that other factors that affect marginal benefit from R&D activities have changed as well. It may be that the externality effects from research activities have become larger as a result of better communication techniques. It may also be that effects from learning by doing have become more important which was implied by the regression in section 5.1. Further, it is possible that the relative “importance” between the R&D- and the goods producing sectors has changed. In section 4.1.2 it was argued that research efforts in the business sector relative to research efforts in the public sector are large in Sweden. Further, in chapter 2 it was noted that basic research is more important than applied research. Because the business sector can be assumed to undertake more applied research this could be an explanation to the decline in the research success parameter and the fact that

Sweden has an average growth rate despite its larger efforts on R&D. However, these effects are just speculations.

The regression in section 5.1 showed that the most important factor to technological progress is accumulation of physical capital and the dynamic diagram in figure 5.3 shows that accumulation of physical capital is actually lower than its equilibrium value. In that diagram, the economy is moving towards a growth path with larger accumulation of physical capital. However, figure 4.3 shows that the accumulation was higher between 1960 and 1975 and has thereafter been substantially lower for a quite long time. So, if the accumulation of physical capital will return to a higher rate is not clear. Then, it could be that figure 5.3 is misleading and the economy is actually closer to equilibrium than what is shown there. Also, as was discussed in section 5.1.3, the regression shows that the contribution to productivity growth from physical capital is fast and the contribution from human capital is slower. If the time horizon was extended this pattern would perhaps be different. But relying on the analysis in section 5.1 and 5.2, it can be concluded that some resources should be taken away from the accumulation of human capital and switched to the accumulation of physical capital in order to increase welfare.

The conclusions from this chapter are solely based on the results from the analysis in this paper. That is, the conclusions are made by looking blindly at the results from these models. This should be kept in mind when evaluating the results; many parameters and calculations are highly uncertain and consequently, the results are uncertain as well. For example, the results found in section 5.1 are not very significant. Then, the results should be taken for what it is, not the ultimate truth. Once again, one must be aware of the assumption underlying the analysis and that the precision of the results could be low. Also, there are many possible ways to study economic growth and the approach taken in this paper is just one among others.

6. Conclusions

This paper questioned the, in an international comparison, high spending on R&D in Sweden. However, the conclusion from the analysis is that the question was unjustified, at least when talking about the share of GDP devoted to R&D which in fact showed to be optimal. But the level of human capital in the R&D sector showed to be higher than optimal. As discussed in section 4.4, the calculations of human capital in the R&D sector are based on the amount of higher education in general, but it does not tell in what sector these workers are employed. Since knowledge production takes place in all parts of the economy, the boundaries between the two sectors are not always clear. But the official statistics in section 4.3 on the share of the labor force working in the R&D sector showed that it is low compared to R&D expenditure as a percentage of GDP. This could mean that the amount of higher education is too high in general, or that there are many workers who are overqualified for their jobs. Then, from a social perspective, some of the high educated workers who are employed in the goods producing sector should be working in the R&D sector instead.

The conclusion that it is more difficult to produce new knowledge in an advanced society than in a less developed society and that this eventually leads to lower growth rates is a quite pessimistic one. However, in this case the question of the optimal level of R&D is not so clear. On the one hand, in order to keep productivity growth rates high, the share of resources going to R&D must constantly be increasing. On the other hand, a constantly increasing share of the R&D sector means that resources in the goods producing sector will eventually be very small. But what if there are developments and advancements in technology in the future that cannot be anticipated up to now? How many anticipated the developments in computer technology in the beginning of the 20th century? In the same way, there may be technology advancements in the future that are almost unthinkable today. And as was noted in the introduction, if one looks at growth rates very far in the past, they have not slowed down when economies have developed towards an advanced state. So, looking at regression analysis, the conclusion is pessimistic but when looking at history it is the other way around. However, this question can certainly not be isolated to an individual economy like Sweden, but the answer to it will of course have consequences to every individual economy.

This paper determined the optimal level of R&D from the viewpoint that the objective is to maximize aggregate consumption. It thereby suggests that the level of higher education is too high. How this level should be adjusted and to what extent it is possible is another question. It is mostly a political issue. But of course, there may be other objectives than optimizing consumption. For example, subsidizing higher education can be done in order to reduce inequalities which in turn will have consequences to the aggregate economy. So what here appears to be a too high level of human capital in the R&D sector may not be true with other objectives.

As was noted in chapter 2, knowledge in this area of research is still very limited. Relationships between different variables are very complex and cannot always be observed. Here this shows up in calculations being inexact. But the contribution of the paper is showing how endogenous growth theory can be applied to the Swedish economy by trying to answer a specific question. However, the scope of this survey is very limited and many improvements could be done by using larger data sets and trying to make the constructed data sets more exact. There are many simplifications, for example when estimating the level of human capital, which could be made in a more exact manner. This survey is mostly based on quantitative methods, but much could certainly be learnt by doing more qualitative research. This could also be done by splitting the economy into different sectors or by looking at different industries in isolation. However, the hope is that this paper has contributed to some extent in analyzing resources in R&D and productivity growth on an aggregate level of the Swedish economy.

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Appendix 1: Derivation of the Romer model

This appendix shows the derivation and the details of the Romer model on endogenous growth presented by Chiang (1992).[59] The focus here is on the technical details and explanations of what the equations, variables and the parameters stand for are quite short. More thorough descriptions of these are given in section 3.2.

The production function for the goods-producing sector is

$$Y = S_Y^{\alpha} L_0^{\beta} \int_0^A x(i)^{1-\alpha-\beta} \, di \tag{A1.1}$$

The total amount of physical capital in the economy is

$$K = \gamma A \bar{x} \Rightarrow \bar{x} = \frac{K}{\gamma A} \tag{A1.2}$$

Using (A1.2), the production function (A1.1) becomes

$$\begin{aligned} Y &= S_Y^{\alpha} L_0^{\beta} \int_0^A x(i)^{1-\alpha-\beta} \, di = S_Y^{\alpha} L_0^{\beta} A \bar{x}^{1-\alpha-\beta} = S_Y^{\alpha} L_0^{\beta} A \left(\frac{K}{\gamma A} \right)^{1-\alpha-\beta} \\ &= S_Y^{\alpha} L_0^{\beta} A^{\alpha+\beta} K^{1-\alpha-\beta} \gamma^{\alpha+\beta-1} \end{aligned} \tag{A1.3}$$

With no depreciation, the change in physical capital will be output less consumption. Because $S_0 = S_Y + S_A$ the equation of motion for physical capital is

$$\dot{K} = Y - C = (S_0 - S_A)^{\alpha} L_0^{\beta} A^{\alpha+\beta} K^{1-\alpha-\beta} \gamma^{\alpha+\beta-1} - C \tag{A1.4}$$

Also, equation of motion for knowledge is

$$\dot{A} = S_A \sigma A \tag{A1.5}$$

The utility function for consumption is assumed to be

$$U(C) = \frac{C^{1-\varphi}}{1-\varphi} \tag{A1.6}$$

[59] Chiang (1992), p. 269-274

(A1.6), (A1.5), and (A1.4) lead together to the optimal control problem

$$\text{Max} \int_0^\infty \frac{C^{1-\varphi}}{1-\varphi} e^{-\rho t} dt$$

$$\text{subject to} \begin{cases} \dot{A} = S_A \sigma A \\ \dot{K} = (S_0 - S_A)^\alpha L_0^\beta A^{\alpha+\beta} K^{1-\alpha-\beta} \gamma^{\alpha+\beta-1} - C \end{cases} \qquad \text{(A1.7)}$$

$$\text{and } A(0) = A_0,\ K(0) = K_0$$

With the definition $\Delta \equiv (S_0 - S_A)^\alpha L_0^\beta A^{\alpha+\beta} K^{1-\alpha-\beta} \gamma^{\alpha+\beta-1}$, the Hamiltonian[60] for this problem is

$$H_C = \frac{C^{1-\varphi}}{1-\varphi} + \lambda_A (S_A \sigma A) + \lambda_K (\Delta - C) \qquad \text{(A1.8)}$$

The first order conditions are

$$\begin{aligned} \frac{\partial H_C}{\partial C} &= C^{-\varphi} - \lambda_K \Rightarrow \lambda_K = C^{-\varphi} \\ \frac{\partial H_C}{\partial S_A} &= \lambda_A \sigma A - \lambda_K \alpha (S_0 - S_A)^{-1} \Delta \Rightarrow \Delta = \frac{\lambda_A \sigma A}{\lambda_K \alpha} (S_0 - S_A) \end{aligned} \qquad \text{(A1.9)}$$

In order to be a maximum, the following equations of motion are necessary

$$\begin{aligned} \dot{\lambda}_A &= -\frac{\partial H_C}{\partial A} + \rho \lambda_A = -\lambda_A \sigma S_A - \lambda_K (\alpha + \beta) A^{-1} \Delta + \rho \lambda_A \\ \dot{\lambda}_K &= -\frac{\partial H_C}{\partial K} + \rho \lambda_K = \lambda_K (1 - \alpha - \beta) K^{-1} \Delta + \rho \lambda_K \end{aligned} \qquad \text{(A1.10)}$$

In steady state, the variables Y, K, A and C grow at the same rate. Combining this with (A1.5), the state condition can be described as

$$\frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \frac{\dot{A}}{A} = \frac{\dot{C}}{C} = S_A \sigma \qquad \text{(A1.11)}$$

Combining this with the expression for λ_K in (A1.9), the growth rate of that variable is

$$\frac{\dot{\lambda}_K}{\lambda_K} = \frac{-\varphi C^{-\theta-1} \dot{C}}{C^{-\theta}} = -\varphi \frac{\dot{C}}{C} = -\varphi S_A \sigma \qquad \text{(A1.12)}$$

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[60] The Hamiltonian is a maximization function similar to the Lagrange multiplier method.

Similarly, the growth rate of λ_A is given by combining (A1.10) and the expression for Δ in (A1.9)

$$\begin{aligned}\frac{\dot{\lambda}_A}{\lambda_A} &= \frac{-\lambda_A S_A \sigma - \lambda_K (\alpha+\beta) A^{-1} \Delta + \rho \lambda_A}{\lambda_A} \\ &= \rho - S_A \sigma - \frac{\lambda_K}{\lambda_A} (\alpha+\beta) A^{-1} \frac{\lambda_A \sigma A}{\lambda_K \alpha} (S_0 - S_A) \\ &= \rho - S_A \sigma - \frac{(\alpha+\beta)\sigma(S_0 - S_A)}{\alpha} \\ &= \rho - \sigma\left(S_0 \frac{\alpha+\beta}{\alpha} - S_A \frac{\beta}{\alpha} \right)\end{aligned} \tag{A1.13}$$

In steady state, the expressions in (A1.12) and (A1.13) must be equal

$$\begin{aligned}&\frac{\dot{\lambda}_K}{\lambda_K} = \frac{\dot{\lambda}_A}{\lambda_A} \Rightarrow -\varphi S_A \sigma = \rho - \sigma\left(S_0 \frac{\alpha+\beta}{\alpha} - S_A \frac{\beta}{\alpha} \right) \\ &\Rightarrow \sigma S_0 \frac{\alpha+\beta}{\alpha} - \rho = S_A \left(\varphi\sigma + \sigma \frac{\beta}{\alpha} \right) \\ &\Rightarrow S_A = \frac{\sigma(\alpha+\beta)S_0 - \alpha\rho}{\sigma(\alpha\varphi + \beta)}\end{aligned} \tag{A1.14}$$

which gives the optimal level of human capital in the R&D sector in steady state. Therefore, using this equation together with (A1.11), the steady state growth rate is given by

$$\frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \frac{\dot{A}}{A} = \frac{\dot{C}}{C} = S_A \sigma = \frac{\sigma(\alpha+\beta)S_0 - \alpha\rho}{\alpha\varphi + \beta} \tag{A1.15}$$

Appendix 2: Statistics

This appendix presents the statistics underlying the calculations in this paper. These statistics come from different sources, but mainly from SCB, historia.se, OECD and World Development Indicators.

	Real GDP (million SEK)[61]	Physical capital stock[62]	Physical capital stock[63]	Physical capital stock[64]	Physical capital stock[65]
1950	553 708	142135,8206			
1951	569 246	171134,5015			
1952	578 599	191669,7653			
1953	598 626	201260,1227			
1954	632 861	210677,6365			
1955	651 921	224721,138			
1956	673 654	244662,342			
1957	689 678	265222,1472			
1958	706 309	286899,6396			
1959	744 188	300167,4448			
1960	771 381	324398,5675			
1961	815 206	343449,3574			
1962	849 926	374816,227			
1963	895 208	401464,5046			
1964	956 272	433054,9049			
1965	992 816	471244,8589			
1966	1 013 575	522296,684			
1967	1 047 686	566535,4601			
1968	1 085 806	600860			
1969	1 140 195	642997,5613			
1970	1 214 007	717175,9509	748813,0953		
1971	1 225 475	805606,5951	842906,2334		
1972	1 253 523	886398,773	929675,2582		
1973	1 303 263	983775,7975	1034000,782		
1974	1 344 944	1121830,04	1180489,078		
1975	1 379 277	1281736,411	1347291,533		
1976	1 393 872		1536336,863		
1977	1 371 623		1766661,529		
1978	1 395 648		1999318,983		

[61] SCB, http://www.scb.se/templates/tableOrChart____26651.asp (2007-01-27)
[62] SCB, Statistiska meddelanden, serie N, 1975:98, appendix 2, 1975 series (Albrecht Ritschl)
[63] SCB, Statistiska meddelanden, serie N, 1984:5.5, appendix 2-3, 1984 series (Albrecht Ritschl)
[64] SCB, Statistiska meddelanden, 9401, N10, appendix 3, 1994 series (Albrecht Ritschl)
[65] SCB, http://www.scb.se/templates/Product____11030.asp (2007-01-27), million SEK, fixed prices

1979	1 449 241		2194452,308		
1980	1 473 428		2556591	2181585,387	
1981	1 470 448		2937171,207	2513665,37	
1982	1 487 992		3262574,473	2810855,941	
1983	1 514 921		3626557,409	3138984,589	
1984	1 579 628			3469221,69	
1985	1 614 217			3802232,498	
1986	1 660 400			4056034,494	
1987	1 717 802			4320334,837	
1988	1 763 607			4716337,653	
1989	1 812 620			5170842,507	
1990	1 830 932			5901509,71	
1991	1 810 402			6698115	
1992	1 788 613			7068790,845	
1993	1 751 808			7571296,62	4446854
1994	1 820 171			7832152,344	4469926
1995	1 891 255				4527923
1996	1 916 614				4627526
1997	1 961 344				4737228
1998	2 033 194				4817172
1999	2 125 202				4916172
2000	2 217 290				5032862
2001	2 240 985				5133182
2002	2 285 726				5226792
2003	2 324 425				5317919
2004	2 420 347				5406428
2005	2 490 615				5525223

	Labor force[66]	Labor force[67]	Hours worked[68]	Hours worked[69]	Hours worked[70]
1950	3405927		650597,5295		
1951	3438057		649164,5283		
1952	3411265		643587,8835		
1953	3402897		636544,0595		
1954	3431083		643787,9515		
1955	3463083		649290,02		
1956	3514932		649413,7798		
1957	3520885		651780,9156		
1958	3546266		646806,0876		
1959	3592091		646180,9093		
1960	3693087		662467,1217		

[66] http://historia.se/ (2007-01-28)
[67] World Development Indicators, http://devdata.worldbank.org/data-query/ (2007-01-28)
[68] http://historia.se/ (2007-01-27), in tens of thousand, totally per year
[69] SCB, http://www.scb.se/templates/tableOrChart____23362.asp (2007-01-27), per week, million hours
[70] Ibid

1961	3723481		668536,5031		
1962	3744551		668098,3421		
1963	3767338		669786,4348		
1964	3821939		668722,2206		
1965	3848096		669069,8676		
1966	3851884		664967,7141		
1967	3811409		646903,0144		
1968	3848369		637401,2932		
1969	3921604		642406,2724		
1970	3997773		654427,8161		
1971	3987976		641178,1864		
1972	4001994		628172,932		
1973	4048027		624705,8541		
1974	4098283		630018,1569		
1975	4178432		632831,8229		
1976	4199511		635746,4416	125,7	
1977	4190405		624208,5837	124,4	
1978	4212912		611152,528	123,1	
1979	4266517		613254,1316	123,9	
1980	4320300	4530222	614251	123,6	
1981	4310800	4518853	612618	124,1	
1982	4288600	4521308	612664	124,2	
1983	4276500	4524170	613410	126,3	
1984	4319900	4515622	624641	128,8	
1985	4364600	4544469	629042	130,7	
1986	4386600	4554901	635926	131,4	127,1
1987	4382300	4590528	641839		128,3
1988	4430300	4652658	653786		130,9
1989	4497100	4708910	664467		133,5
1990	4503700	4748188	668371		134,8
1991	4421500	4733020	652544		132
1992	4203900	4641595	626869		127,3
1993	3988400	4535920	600984		120,8
1994	3958600	4508909	608678		122,6
1995	4027005	4557717	620314,5753		125
1996	3994085	4548183	618703,0919		124,7
1997	3939468	4503968	612181,3625		123,3
1998	4000653	4489520	621212,8959		123,8
1999	4086297	4521683	638236,2697		128,7
2000	4186351	4608398	644936,8515		130,1
2001		4644706			130,8
2002		4654992			128,9
2003		4681796			127
2004		4660649			126,7
2005		4530222			130,5

	Consumption (million SEK)[71]	Private consumption (million SEK)[72]	Public consumption (million SEK)[73]	Inflation private consumption[74]	Inflation public consumption[75]
1950		21505,44347	4164,63673	2,73	1,74
1951		23988,85382	5201,738292	12,71	19,17
1952		26567,01895	6325,574116	6,77	15,25
1953		27674,16185	6970,187734	1,66	1,34
1954		29238,06975	7302,923257	1,56	-0,17
1955		31130,97933	7934,523018	3,17	6,41
1956		33661,35417	8771,465427	5,07	5,21
1957		35465,1849	9771,482423	3,78	8,12
1958		37907,76125	10397,15366	4,37	1,67
1959		39804,11248	11099,19826	1,35	1,64
1960		42125,38578	11931,46529	4,01	5,66
1961		45534,88223	12956,06463	2,27	4,97
1962		49181,50489	14838,42605	3,96	7,82
1963		53282,30982	16575,90447	3,00	1,99
1964		57714,34881	18377,08953	3,56	7,69
1965		63717,60652	20866,7316	5,45	8,43
1966		69214,85516	24136,1143	6,56	9,68
1967		74619,59478	27071,19636	5,40	7,19
1968		79052,98956	30269,03656	1,75	4,62
1969		85349,6369	33254,56297	3,38	4,22
1970		92747,34282	38600,88733	5,00	7,35
1971		99921,82043	43744,65961	7,64	10,90
1972		109978,1555	48365,11551	6,41	7,93
1973		121346,711	53709,54611	7,56	8,31
1974		138386,4724	62031,80902	10,32	12,13
1975		157776,1643	74676,15042	10,91	15,06
1976		182468,0315	88277,90349	11,04	14,16
1977		200029,6645	106001,577	10,77	16,72
1978		221699,9051	120014,23	11,62	9,62
1979		245103,6845	136292,4534	7,95	8,41
1980		273330	158009,9407	12,42	13,34
1981		305552	174945,5476	12,08	8,19
1982		340036	190782,2662	10,49	8,07
1983		369442	209193,8017	10,85	8,73
1984		403775	227151,3435	7,71	6,26
1985		443671	245802,0123	7,01	5,88
1986		487328	264355,8462	5,18	6,29
1987		537868	277678,8871	5,56	4,09

71 http://www.konj.se/statistik/konjunkturlaget/bnpochefterfragan.4.7d810b7d109c0650979800018342.html (2007-01-28), fixed prices (2005) (Konjunkturinstitutet and SCB)
72 http://historia.se/ (2007-01-28), nominal prices
73 Ibid
74 http://historia.se/ (2007-01-28), percent per year
75 Ibid

1988		584354	295537,361	6,06	5,54
1989		632744	327697,0216	7,03	8,84
1990		692668	377854,7235	9,91	12,41
1991		771310	400356,387	10,34	3,13
1992		777324	408566,845	2,21	2,10
1993	985809	796370	412365,7298	5,68	0,70
1994	1003475	834502	422803,4277	2,95	3,17
1995	1012264	866844,7244	436531,6584	2,79	3,70
1996	1028935	892239,6189	458023,9549	1,27	4,09
1997	1054786	933415,655	466145,49	1,89	2,77
1998	1086114	968980,3291	490312,7069	0,82	1,88
1999	1127493	1017622,152	515327,5888	1,18	3,46
2000	1183523	1069367,051	541739,1134	0,12	6,42
2001	1188838				
2002	1206391				
2003	1227826				
2004	1255429				
2005	1284965				
2006	1322842				
2007	1374121				
2008	1419372				

	Population[76]	**GDP per hour worked in G7 countries (US dollar)**[77]	**Amount of university degrees**[78]	**Advanced level students**[79]	
1950	7 046 920				
1951	7 098 740				
1952	7 150 606				
1953	7 192 316				
1954	7 234 664				
1955	7 290 112				
1956	7 341 122				
1957	7 392 872				
1958	7 436 066				
1959	7 471 345				
1960	7 497 967				
1961	7 542 028				
1962	7 581 148				
1963	7 627 507				
1964	7 695 200				

[76] SCB, http://www.scb.se/templates/Product____25785.asp (2007-01-27)
[77] OECD, http://www.oecd.org/topicstatsportal/0,2647,en_2825_30453906_1_1_1_1_1,00.html (2007-01-20)
[78] SCB, *Statistisk årsbok 1975*, p. 322, Statistisk årsbok 1978, p. 338 and http://www.scb.se/templates/subHeading____76738.asp (2006-09-30)
[79] SCB, http://www.scb.se/templates/subHeading____75811.asp (2006-09-30)

1965	7 772 506		7852	
1966	7 843 088		8949	
1967	7 892 774		10421	
1968	7 931 193		15064	
1969	8 004 270		17151	
1970	8 081 142	17,1	20268	
1971	8 115 165	17,9	20909	
1972	8 129 129	18,7	21651	
1973	8 144 428	19,5	21323	
1974	8 176 691	19,8	19311	
1975	8 208 442	20,3	15081	
1976	8 236 179	21,0	14833	
1977	8 267 116	21,6	29 953	12 142
1978	8 284 437	22,2	32 479	12 175
1979	8 303 010	22,7	32 768	12 108
1980	8 317 937	22,9	34 526	12 083
1981	8 323 033	23,5	35 282	12 400
1982	8 327 484	23,7	35 665	12 630
1983	8 330 573	24,2	36 097	13 119
1984	8 342 621	24,8	33 905	13 192
1985	8 358 139	25,5	31 761	11 801
1986	8 381 515	26,0	30 736	12 105
1987	8 414 083	26,5	31 007	12 439
1988	8 458 888	27,1	30 850	12 920
1989	8 527 036	27,7	30 111	13 078
1990	8 590 630	28,4	29 582	13 247
1991	8 644 119	28,9	32 113	13 984
1992	8 692 013	29,7	33 741	14 348
1993	8 745 109	30,2	34 010	15 383
1994	8 816 381	30,8	34 271	15 493
1995	8 837 496	31,2	32 284	15 523
1996	8 844 499	31,8	35 388	16 619
1997	8 847 625	32,5	35 347	17 688
1998	8 854 322	33,0	37 648	18 936
1999	8 861 426	33,9	40 109	18 854
2000	8 882 792	34,8	40 480	18 664
2001	8 909 128	35,4	43 864	18 958
2002	8 940 788	36,2	48 739	19 434
2003	8 975 670	37,0	52 906	20 087
2004	9 011 392	37,8	57 100	19 884
2005	9 047 752	38,5	7852	12 142

	University students[82]
1960	36909
1961	40184
1962	44460
1963	50114
1964	59643

	Amount of advanced level degrees[83]
1970	1436
1971	1404
1972	1370
1973	1480
1974	1499
1975	1208
1976	901
1977	890

	R&D expenditures (percentage of GDP)[80]	Researchers per million people[81]
1984	0,026	
1985	0,027	
1986	0,028	
1987	0,029	
1988	0,0285	
1989	0,028	
1990	0,0275	
1991	0,027	
1992	0,03	
1993	0,0315	
1994	0,033	
1995	0,0337	
1996	0,0343	
1997	0,0352	4162,841
1998	0,0361	
1999	0,037	4503,295
2000	0,0398	
2001	0,0425	5167,474
2002	0,0405	
2003	0,039	5332,614
2004	0,038	5415,739

	Average years of schooling[84]	Second level schooling (percent)[85]	Higher level schooling (percent)[86]
1960	7,65	18,4	4,3
1965	7,65	22	4,3
1970	7,47	27,1	4,7
1975	8,44	32,2	7
1980	9,47	35,7	8,7
1985	9,22	24,5	9,6
1990	9,57	27,6	10,4
1995	11,23	44,1	11,9
2000	11,36	42,9	13,1

[80] SCB and OECD, http://www.scb.se/templates/tableOrChart____151028.asp (2007-01-28)
[81] World Development Indicators, http://devdata.worldbank.org/data-query/ (2007-01-28)
[82] SCB, *Statistisk årsbok* 1963, p. 299 and *Statistisk årsbok* 1966, p. 305
[83] SCB, *Statistisk årsbok* 1982/1983, p. 327
[84] Barro, Robert J. and Jong-Wha Lee, International Data on Educational Attainment: Updates and Implications (CID Working Paper no. 42)
[85] Barro, Robert J. and Jong-Wha Lee, International Data on Educational Attainment: Updates and Implications (CID Working Paper no. 42), highest level attained, percentage of the population aged 25 and over
[86] Barro, Robert J. and Jong-Wha Lee, International Data on Educational Attainment: Updates and Implications (CID Working Paper no. 42), highest level attained, percentage of the population aged 25 and over