2001/10 September 2001 Documents

Statistics Norway
Research Department

Ole Christian Moen

Nordic Economic Growth in Light of New Theory:
Overoptimism about R&D and Human Capital?

Contents

1 Introduction **1**

2 Modeling Growth **5**

2.1 Background 5

2.2 The Model 8

2.3 Specification 17

3 Data Material **21**

4 A Comparative View **25**

4.1 GDP per capita 25

4.2 Education 27

4.3 R&D 28

5 Results **29**

5.1 Preliminary examination 29

5.2 Estimation 30

6 Conclusion **39**

References **41**

A Derivations **46**

B Data **48**

B.1 Measuring human capital, R&D and GDP per capita 48

B.2 Data set 53

C Regressions **55**

D Related literature **63**

1 Introduction[1]

> "The good Education of Youth has been esteemed by wise Men in all Ages, as the surest Foundation of the Happiness both of private Families and of Commonwealths. Almost all of Government have therefore made it a principal Object of their Attention, to establish and endow with proper Revenues, such Seminaries of Learning, as might supply the succeeding Age with Men qualified to serve the Public with Honour to themselves, and to their Country."
>
> Benjamin Franklin, 1749, Proposals Relating to the Education of Youth in Pennsylvania.[2]

The idea that education is important for economic growth has existed for a long time. Recently, that an educated population is vital for the economy to grow has been emphasized and a number of theories trying to explain the link between education and economic growth have emerged. In addition to education, economic theory points out R&D as the main engine of growth. However, it is not only economists that believe that education and R&D are important. Since World War II, the Nordic countries[3] and the other OECD economies have devoted more and more resources to these activities.

Over the last 50 years, time spent accumulating skills through formal education has increased. The average level of schooling in the total population was in 1995 over 11 years in all Nordic countries. There are cross-country differences in the increase in educational attainment. For instance, average years of schooling has increased by almost four years in Finland from 1960 to 1995, while in Denmark over the same period, average years of schooling increased by only one year.

[1] I thank the Research Department, Statistics Norway, for financial support and I am grateful to Prof. Tor Jakob Klette at the University of Oslo, my supervisor, for useful and encouraging comments, given in an inspiring manner. I am also grateful to the researchers at the Division of Microeconometrics, Statistics Norway, for creating a stimulating working environment, in particular, I have received helpful advice and comments from Torbjørn Hægeland. My close friends, Olav Chen and Ola Storberg, have given useful comments. The responsibility for any remaining errors stays with the author.

[2] Quoted from Storsletten and Zilibotti (1999).

[3] Throughout this paper, I will use the term "the Nordic countries" on the four countries: Norway, Sweden, Denmark and Finland. The reason is convenience. Iceland, the Faroe Islands and Åland, please accept my apology.

A second pattern in the Nordic countries and the other OECD economies since 1945, is that the search for new ideas has intensified. Both the number of people engaged in R&D activities and the R&D expenditure as a percentage of GDP have increased substantially. It is Sweden and Finland that currently devote most resources to R&D in the Nordic countries. In 1995, Sweden and Finland spent about three and two percent of their GDP on R&D. In the same year, the R&D expenditure as a percentage of GDP in Norway and Denmark was 1.7 and 1.9, respectively. 30 years earlier, all the countries devoted about one percent of their GDP on R&D activities.

The period since World War II has also been a period of large economic growth. Over this period of about 50 years, the average annual growth rate of per capita GDP in the Nordic countries have been around three percent. However, there are major cross-country differences. From 1945 to 1995, Norway experienced an average growth of per capita GDP of 3.4 percent per year, whereas over the same period of time, the average annual growth in Sweden was 2.3 percent. As a result of these growth rate differences, in 1995, the GDP per capita level in Norway was over four times the level in 1945, whereas the GDP per capita level in Sweden only doubled.

In this paper I will examine if it is possible to explain the growth in Nordic per capita GDP and the cross-country differences with R&D and human capital investments. A number of authors, e.g. Mankiw et al. (1992), Lichtenberg (1993), Andrés et al. (1996) and Barro (1997), have presented empirical investigations in the same spirit[4]. However, their theoretical frameworks differ and they do not focus on the Nordic countries, but use samples consisting of a large number of countries. Data from the Nordic countries are, traditionally, of high quality and the Nordic countries are quite similar societies. Thus, in my sample, poor data and omitted variables will, hopefully, cause less problems than in the above mentioned empirical investigations and the analysis could thus perhaps help answering the question if some of the Nordic countries would gain from adjusting their R&D and education policy.

Section 2 starts with a brief history of economic growth theory, emphasizing endogenous growth models. It also offers an explanation of why I have chosen a Schumpeterian growth model as a framework for my analysis. In section 2.2 a formal growth model,

[4]Surveyed by e.g. Topel (1999) and McGratten and Schmitz (1999).

admittedly only one of many possible candidates, is presented and the key results are discussed. The model is suggested in Howitt (2000). However, the model used in the present study is extended to include accumulation of human capital. In addition to including traditional Solow-type determinants of GDP per capita, this model predicts a higher steady-state level of per capita GDP the higher the R&D expenditure as a percentage of GDP and the higher the *level* of the human capital stock are. Outside steady-state, controlling for variables such as the human and physical capital stock and the country's technological level, the model predicts a higher per capita GDP *growth rate* the higher the R&D expenditure as a percentage of GDP is. In section 2.3 the empirical specification is derived and some alternative specifications are suggested.

Section 3 discusses the data that I use[5]. In particular, I focus on the measurement problems of human capital and R&D expenditure and I discuss the improvements in measuring the former that have taken place by de la Fuente and Doménech (2000).

Section 4 gives an overview of the development of GDP per capita, educational attainment and resources devoted to R&D in the Nordic countries since 1945. Focus is on cross-country differences. Section 4 also includes plots of GDP per capita *growth rates* against GDP per capita *levels,* finding a negative relationship in support of the convergence hypothesis.

The results of the empirical investigation are presented in section 5. It starts with a preliminary examination of the impact of education and R&D on growth, plotting GDP per capita *growth rates* against the level of the human capital stock and the level of the R&D expenditures. I find a significant *negative* relationship between both the level of human capital and growth and between R&D expenditures and growth. However, I conclude that one cannot draw definite conclusions from such an investigation, since there are substantial correlation between different determinants of growth. In section 5.2 the parameters of the model developed in section 2 are estimated. When using pooled data at five-year intervals, the empirical results and the model's predictions are consistent except with respect to the impact of R&D expenditure on growth. Even though the model explains a large part of the interspatial differences in economic growth, a stability analysis concerning the length of the intervals in the sample show that in particular the

[5] A more thorough discussion of the data and the data used are given in Appendix B.

coefficient on human capital is unstable, throwing doubt on the model's predictions. The most robust coefficient is on the "initial level of GDP", always negative, giving support to the convergence hypothesis. The coefficient on R&D expenditure is stable, but negative, throwing even more doubt on the theoretical model's predictions.

Section 6 offers some concluding remarks, recognising the problem of drawing strong conclusions, given the data quality and due to the small number of observations in my sample. However, the positive impact of R&D and education on economic growth that several papers take for granted[6], do not show up in data. Thus, in light of the empirical results, I ask the question if endogenous growth advocates have been too optimistic about the role human capital and R&D have in explaining growth[7].

[6] e.g. "In our analysis we take as given that human capital is important for growth, rather than specifying exactly through which routes", Henrekson, Jonung and Stymne (1995), p. 274.

[7] Appendix D gives a brief overview of related literature, emphasizing models that give a more modest role to education and R&D in determining a country's economic growth.

2 Modeling Growth

2.1 Background

Maddison (1991) distinguishes between analyses concerning "ultimate" and "proximate" factors influencing the development of economies. "Ultimate" factors are factors like institutions, ideologies, historical accidents and pressures from socio-economic interest groups. These "ultimate" features of an economy are all part of the traditional domain of historians and are virtually impossible to quantify. Early contributors of such analyses were Smith and Malthus in the 18th century and later Ricardo and Marx in the 19th century. Schumpeter presented analyses of "ultimate" factors in the 20th century. Analyses of "proximate" factors are mainly based on measures and models developed by economists and statisticians, trying to "explain" growth by measuring inputs like labour and capital.

In this study, I will analyze the "proximate" factors influencing economic growth. It will take form as an empirical investigation of the growth performance of the different Nordic countries, trying to explain Nordic cross-country differences in general and to quantify the importance of education and research on economic growth in particular. Wanting to conduct such a *quantitative* analysis, it is a natural first step to find or construct a theoretical model explaining the link between research, education and growth. In addition, the theoretical model has to suit itself to empirical implementation. However, the literature on economic growth models is vast and there are several different branches within this field[8].

The traditional neoclassical theory of growth is usually traced back to Solow (1956) and Swan (1956). From initially only to include one factor that could be accumulated over time, physical capital, the theory has been developed further in several ways, for example by including accumulation of human capital. One of the main results from this literature is that technological progress is needed to accomplish sustained economic growth. However, the theory does not explain what causes this technological progress. In neoclassical growth theory, the fundamental source to economic growth is exogenous. Even though the theory has been quite successful in explaining the cross-country variation in economic growth,

[8] The literature in general is surveyed by Barro and Sala-i-Martin (1995). The literature on the impact of education and research on economic growth in particular is surveyed by Hægeland and Møen (2000).

the theory is not satisfactory when it comes to explaining *why* economic growth takes place. The main reason for this is that neoclassical growth theory does not include an accurate and realistic description of the process of innovation (Mankiw, 1995). Since this analysis concerns the impact of education and research on growth, it is obvious from the above discussion that a model taken from the neoclassical growth theory would not be suitable as a framework.

Endogenous growth theory emerged in the 1980s[9]. Advocates of this theory developed models that tried to explain persistent growth without the assumption of exogenous advances in technology. They emphasized that economic growth is an endogenous outcome of an economic system and is affected by private and public sector choices. In several endogenous growth models, different kinds of externalities are the key factors behind growth. One is the well-known AK-model, where the production function shows constant returns to scale to a broad definition of capital, including knowledge. Knowledge is a by-product of all the firms' production in the economy and all the firms' production increases with the total level of knowledge in the economy. This gives the model endogenously determined technological progress and endogenously determined sustained economic growth.

Another branch of endogenous growth models operates with several sectors in the economy. Such a model is presented in Mankiw (1995). The economy in this model has two sectors; one consisting of firms producing final goods and services and one consisting of research universities producing knowledge. This knowledge is freely used in both sectors. The level of the persistent growth rate of the economy depends on the number of workers employed in the sector of research universities. Thus, this model is a theory on the link between resources devoted to research in a country and that country's economic growth performance. Jones (2000) presents a more complex model in the same spirit, which breaks up the stock of knowledge into a stock of human capital and a stock of ideas. The long run growth rate of the economy is in this model determined by the share of the population accumulating human capital and the share engaged in research activities. Obviously, these models would suit better as a framework for answering the questions stated in section 1 than a neoclassical growth model.

The models referred to above do not, however, include several important "facts" about

[9]See Romer (1994) for a detailed description of how and why endogenous growth theory emerged.

the creation of knowledge, as pointed out in Mankiw (1995). First, even though knowledge is largely a public good, a lot of research is done in firms that are driven by the profit motive. Second, when one firm innovates, other firms build on that innovation in order to produce the next generation of innovations. Third, research is profitable because innovations give firms temporary monopolies (either because of the patent system or because there is an advantage of being first). In addition, the models mentioned above do not take into account that even though there are positive externalities concerning research and innovations, for example to the researchers of tomorrow, there could be negative externalities as well. Clearly, for the owner of a patent on an existing product it is not good for business if a better substitutable product is invented. Romer's (1990) neoclassical growth model[10], augmented to give an endogenous explanation of the source of the technological change incorporates the first and second "fact" about the creation of knowledge. He makes the unrealistic assumption, though, that no product is ever driven out of the market by new or quality improved products. However, Neo-Schumpeterian models of growth incorporates all the above "facts", without making this unrealistic assumption.

Neo-Schumpeterian growth theory emerged in the late 1980s. However, the main idea behind the models from this theory, the idea of "Creative Destruction", that make them different from other endogenous growth models, was put forward in 1942 by Joseph Schumpeter in his famous book *Capitalism, Socialism and Democracy* (p.83):

> "The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets,...(This process) incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism."

By modelling the process of "Creative Destruction", the advancement of technology as a result from inventions of new and better products by firms competing for market power and monopoly profit, Neo-Schumpeterian growth theory incorporates all the "facts" concerning research discussed above. Thus giving a fairly accurate and realistic description of

[10] See Dinopoulus and Thompson (2000) for a cross-country empirical investigation using this model as a framework.

the process of innovation. Such models explain *why* people engage in R&D activities, as oppose to for example the model by Jones (2000), where the ratio of researchers to population is given exogenous. In Aghion and Howitt (1992), a classical Neo-Schumpeterian growth model, the number of researchers in equilibrium is determined by several parameters and variables, including the total endowment of skilled labour. However, one shortcoming of several of these models, including Aghion and Howitt (1992), is that they do not adequately take into account the role of human capital, which is at most viewed as an input in the research process (Frantzen, 2000).

Even though Neo-Schumpeterian growth models do not describe the acquisition of human capital in detail, I will choose such a model as a framework for this analysis, namely the model presented by Howitt (2000). The main reason is that Neo-Schumpeterian growth models are the growth models that have the most detailed description of the link between resources devoted to R&D and the persistent growth rate of the economy. In addition, the model by Howitt (2000) includes a more detailed description of the accumulation of human capital than Aghion and Howitt (1992), identical to the description in the neo-classical models including human capital, which have successfully explained cross-country differences[11].

2.2 The Model

The model I will use as a framework for this analysis is presented below. The only difference between this model and the model presented in Howitt (2000) is that it allows human capital to be accumulated. The model in Howitt (2000) allows only physical capital to be accumulated, but an extension of the model to include human capital is suggested and the extended model's steady-state equation is given. However, since the derivation of the extended model and a discussion of its conclusions are not included in Howitt (2000), I present the relations underlying the model and discuss its main results below[12].

Production relations

Consider a single country in a world economy with m different countries. There is one final good, produced under perfect competition by labour and a continuum of intermediate

[11] See Mankiw et al. (1992) and Lichtenberg (1993) for explanations of cross-country differences using neo-classical growth models as frameworks.

[12] See Appendix A for some of the derivations.

products, according to the production function

$$Y_t = \int_0^{N_t} A_t(i) F(x_t(i), L_t/N_t) di \tag{1}$$

where Y_t is the country's gross output, L_t the flow of labour used in production, N_t the number of different intermediate products produced and used in the country, $x_t(i)$ the flow output of intermediate product i and $A_t(i)$ a productivity parameter attached to the latest version of intermediate product i where $i \in [0, N_t]$, all at date t. $F(.)$ is an integrable constant returns production function. I will focus on the well known Cobb-Douglas case[13]

$$F(x_t(i), L_t/N_t) = (x_t(i))^{\lambda}(L_t/N_t)^{1-\lambda}, \qquad 0 < \lambda < 1 \tag{2}$$

There is no international trade in goods or factors. The only connection between countries is through technology transfer, as will be explained later. Labour supply and population size are identical. They grow at the exogenously given fixed rate g_L. The number of intermediate products grows as a result of imitation, not deliberate innovation. Imitation is limited to domestic intermediate products, attaching to each new product the same productivity parameter as the productivity parameter to a randomly chosen existing product. Each person has the same propensity to imitate[14], $\varepsilon > 0$, making the degree of imitation proportional to the number of individuals in the economy. Thus, the aggregate flow of new products is

$$\dot{N}_t = \varepsilon L_t \tag{3}$$

Since the population growth rate g_L is constant, the number of workers per product L_t/N_t converges monotonically to the constant

$$\ell = g_L/\varepsilon \tag{4}$$

[13] See Martimort and Verdier (2000) for a more detailed description of the links between the firms' microeconomic decisions and macroeconomic growth than the assumption of a Cobb-Douglas production function can give.

[14] The term imitation is here used on an invention of an entirely new product, as oppose to a quality improved product. In the literature, this is also called a horizontal invention.

If we assume this convergence has already occurred, we get

$$\ell = L_t/N_t \quad \text{for all } t \tag{5}$$

The model thus have a very simple structure when it comes to how new products are created. Horizontal innovations are not resulting from profit-seeking behaviour, but as a consequence from the population's exogenous given propensity to imitate already existing products. The model does not explain why people imitate. In addition, the assumption that imitation is limited to domestic products, is a strong simplification. The model could be extended to allow for a more realistic description of the process of horizontal innovations, see e.g. Segerstrom (2000), but this would increase the complexity of the analysis substantially..

(5) inserted in (2) then gives

$$F(x_t(i), L_t/N_t) = (x_t(i))^{\lambda}\ell^{1-\lambda} \tag{6}$$

Final output can be used interchangeably as a consumption good or a capital good (human and physical), or as an input to R&D. Each intermediate product i at date t is produced according to the production function

$$x_t(i) = ((K_t(i))^{\gamma}(H_t(i))^{1-\gamma})/A_t(i), \qquad 0 < \gamma < 1 \tag{7}$$

where $K_t(i)$ and $H_t(i)$ are, respectively, physical and human capital used in the production of intermediate product i at date t. The production function for intermediate products has then constant returns in human and physical capital. Division by $A_t(i)$ in equation (7) indicates that the capital-intensity in the production of a unit intermediate product is increasing with the complexity of this product, reflected through a higher $A_t(i)$.

Innovations are targeted at specific intermediate products. Each innovation creates an improved version of the existing product. Unlike horizontal innovations, vertical innovations are a result of profit-seeking behaviour. The innovator of a quality improved product replaces the incumbent monopolist and earn monopoly profit until the next innovation occurs in that sector, giving an incentive to conduct R&D. The incumbent monopolist of each product operates with a price schedule given by the marginal product of the intermediate good from the final output sector and a cost function. Given that the monopolists maximize their profits and by solving the maximization problem we get[15]

[15] See Appendix A for a detailed derivation.

$$x_t(i) = x_t = (K_t^{\gamma} H_t^{1-\gamma})/(N_t A_t) \tag{8}$$

where x_t is the quantity all monopolists choose to produce and K_t and H_t are the total supply (assumed equal to total demand) of physical and human capital, respectively. A_t is the average productivity parameter across all sectors, $\int_0^{N_t} A_t(i)di/N_t$. The reason why all monopolists choose to produce the same quantity, is that both the marginal revenue and the marginal cost schedules are proportional to $A_t(i)$. Since the value of $A_t(i)$ is the only difference between the intermediate firms, they will decide on the same quantity when setting marginal revenue equal to marginal cost.

Define $k_t = K_t/A_tL_t$ and $h_t = H_t/A_tL_t$ as physical and human capital per "effective worker", respectively. By substituting from (8) into (2) and then into (1) we get a Cobb-Douglas function relating output per "effective worker" to physical and human capital per "effective worker"

$$Y_t/(L_tA_t) = k_t^{\alpha} h_t^{\beta} = f(k_t, h_t) \tag{9}$$

where $0 < \alpha = \lambda\gamma < 1, 0 < \beta = \lambda(1-\gamma) < 1$ and $0 < \alpha + \beta = \lambda < 1$

Substituting from (8) into the necessary condition for profit maximization[16] of each monopolist and using the definitions above, yields the equilibrium interest rate and the equilibrium wage. As in Mankiw et al. (1992), I assume that human capital depreciates at the same rate δ as physical capital.

$$r_t = C_r \alpha k_t^{\alpha-1} h_t^{\beta} - \delta = C_r \partial f(k_t, h_t)/\partial k_t - \delta \tag{10}$$

$$w_t = C_w \beta k_t^{\alpha} h_t^{\beta-1} - \delta = C_w \partial f(k_t, h_t)/\partial h_t - \delta \tag{11}$$

where C_r and C_w are constants depending on α and β only. It can then be shown that each local monopolist will earn a flow of profits proportional to its productivity parameter $A_t(i)$, namely

$$\pi_t(i) = A_t(i)\ell(1-\lambda)\lambda k_t^{\alpha} h_t^{\beta} = A_t(i)\ell(1-\lambda)\lambda f(k_t, h_t) = A_t(i)\widetilde{\pi}_t(k_t, h_t)\ell \tag{12}$$

[16] These are given in Appendix A.

Innovations

Vertical innovations result from domestic R&D. An innovation in sector i in a country results in a new generation of that country's intermediate product i with a productivity parameter equal to the worldwide "leading-edge technology parameter", $A_t^{\max}$, defined as

$$A_t^{\max} = \max\{A_{jt}(i) : i \in [0, N_{jt}], j = 1, ..., m\} \tag{13}$$

where j denotes a variable specific to country j (m countries, N_{jt} intermediate products in country j at date t). Thus, unlike horizontal innovations, vertical innovations are not limited to domestic products. This technology transfer is the only connection between countries. Each vertical innovation, no matter in what sector or country it is invented, has the highest productivity parameter attached to it. The model thus assumes that, at a given date, a new idea is never adopted unless it, at the same date, surpasses the current worldwide state of the art.

Allowing for trade in goods, it is a reasonable assumption that an innovation in a sector of the domestic economy that has a lower productivity parameter than a comparable intermediate good in another country, may not be able to survive competition from abroad. However, in our model this is a strong assumption, since we have assumed no trade in goods (which itself is a strong assumption). Eaton and Kortum (2001) have developed a model where trade in goods transfers technology between countries, thus making the assumption that a new idea is never adopted unless it surpasses the current worldwide state of the art more realistic. One of their models' conclusions is that research intensity does not depend on openness to trade. There are two offsetting effects; access to foreign markets increases potential profits that a successful idea can earn, but competition from abroad makes it more difficult to have a marketable idea in the first place. Thus opening for trade in our model, making the model's technology transfer mechanism more realistic, may not influence the model's conclusions. So even though assuming no trade in goods, working with the technology transfer mechanism described above could be reasonable.

The Poisson arrival rate ϕ_t of innovations in each sector is

$$\phi_t = \mu n_t \; ; \qquad \mu > 0 \tag{14}$$

where μ is a parameter indicating the productivity of R&D, and where n_t is the productivity-adjusted quantity of final output devoted to R&D in each sector; $n_t = (\frac{R\&D_t}{N_t})/A_t^{\max}$. $R\&D_t$

is the total amount of output devoted to R&D at date t. The division by $A_t^{\max}$ takes into account the force of increasing complexity; as technology advances, the resource cost of further advances increases proportionally. ϕ_t is a measure of the rate of what we previously called "creative destruction". We assume that the productivity parameter of R&D is identical for all sectors and that the total amount devoted to R&D is shared equally by the different sectors.

Suppose that R&D expenditures are subsidized at the proportional rate $\psi < 1$. The subsidy rate, ψ, is a proxy for all distortions and policies that impinge directly on the incentive to innovate. It can be negative, in which case the distortions and policies favouring innovation are outweighed by those discouraging it.

The level of R&D expenditures is given by an arbitrage condition

$$1 - \psi = \frac{\mu}{A_t^{\max}} \frac{A_t^{\max} \pi_t(k_t, h_t)\ell}{r_t + \mu n_t} = \mu \frac{\pi_t(k_t, h_t)\ell}{r_t + \mu n_t} \tag{15}$$

which says that net marginal cost of R&D per intermediate product, $(1 - \psi)$, is equal to the marginal effect, $\mu/A_t^{\max}$, of R&D per product on the arrival rate times the expected discounted value of the flow of profits that a successful innovator will earn. The discount rate applied in (15) is the rate of interest plus the rate of creative destruction μn_t; the latter the instantaneous flow probability of being displaced by an innovation[17]. Equation (4), (10) and (15) can be solved for the country's R&D intensity, n_t, at any given date as a function of the country's physical and human capital intensities at the same date, k_t and h_t, and the parameters $\psi, \mu, g_L, \delta, \lambda, \gamma$ and ε. I will assume that the resulting n_t is positive and that δ, λ, γ and ε are equal across countries; i.e. the countries share the same depreciation rate, production function and imitation rate. Let θ describe the country specific parameters

$$\theta = (\psi, \mu, g_L) \tag{16}$$

We can now write n_t as a function of k_t, h_t and θ

$$n_t = \widetilde{n}(k_t, h_t; \theta) \tag{17}$$

[17] See Aghion and Howitt (1992) for a more detailed description of this arbitrage condition.

with partial derivatives

$$\widetilde{n}_k > 0,\ \widetilde{n}_h > 0,\ \ \widetilde{n}_\psi > 0,\ \ \widetilde{n}_\mu > 0,\ \ \widetilde{n}_{g_L} > 0 \tag{18}$$

The positive impact of a higher k_t or h_t on the R&D intensity n_t can be explained as follows; an increase in k_t or h_t induce more R&D by raising production and thereby profit (see equation (12)). In addition, an increase in k_t lowers the interest rate used for discounting this profit (see equation (10)), inducing even more R&D. In contrast, a higher h_t increases the interest rate used for discounting (see equation (10)), inducing less resources devoted to R&D. However, this latter effect is not strong enough to offset the effect on R&D through higher profit. A higher subsidy rate lowers the cost of R&D inducing a higher R&D intensity. A higher μ increases the marginal effect of R&D on the arrival rate, making it easier to get monopoly profit. This effect tends toward a higher n_t. The effect a higher μ has on the discounting rate, the probability of being replaced by another monopolist increases, is not strong enough to offset this positive impact on n_t. A faster population growth, a higher g_L, induces more R&D through a "scale effect," by increasing the equilibrium number ℓ of people per product and in that way increasing the monopolists' profit (see equation (12)).

Productivity Growth, Physical and Human Capital Accumulation

The average productivity parameter A_t in a country grows as a result of innovations in the different sectors of the domestic economy replacing the existing productivity parameter in that sector with the worldwide leading-edge parameter $A_t^{\max}$. The rate of increase in this average equals the flow rate of innovation μn_t times the average increase in A_t. The average increase in A_t is $(A_t^{\max} - A_t)$, since the innovations are uniformly distributed across all sectors (we have assumed that the total amount devoted to R&D is shared equally by the different sectors). We then get

$$\dot{A}_t = \mu n_t (A_t^{\max} - A_t) \tag{19}$$

With μn_t positive and $A_t^{\max}$ constant, all the economies' A_t's will converge to $A_t^{\max}$.

Assume instead that the world rate of technological progress at date t is given by[18]

$$g_t = \dot{A}_t^{\max}/A_t^{\max} \tag{20}$$

That means that the country with the highest rate of creative destruction, μn_t, will eventually become the country with the highest average productivity parameter A_t, since the country will have relatively more intermediate products that are up to date.

If we let $a_t = A_t/A_t^{\max}$ denote a country's average productivity relative to the leading edge, it follows from (17), (19) and (20) that

$$\dot{a}_t = \mu\widetilde{n}(k_t, h_t; \theta)(1 - a_t) - a_t g_t \tag{21}$$

Equation (21) describes the mechanism through which technology transfer makes a country's average productivity growth rate converge to the world rate of technological progress. Starting from a situation with no growth in a_t, an increase in the R&D intensity will temporarily cause a_t to grow with a positive rate. However, as $(1 - a_t)$ is getting smaller and $a_t g_t$ is getting bigger, the growth rate of a_t will decrease and converge to zero, resulting in a growth rate of A_t equal to g_t. It can be easily shown that the differential equation (21) is stable. Hence a country's relative productivity level a_t will converge to a steady-state level, given a fixed R&D intensity and a fixed world rate of technological progress.

Assume that the constant investment rates for physical and human capital are s_K and s_H, respectively. s_K and s_H measure the fraction of output invested in the two forms of capital; $s_K = (\dot{K}_t + \delta K_t)/Y_t$ and $s_H = (\dot{H}_t + \delta H_t)/Y_t$. Since $k_t = K_t/A_t L_t$ and $h_t = H_t/A_t L_t$ it follows from (17) and (19) that

$$\dot{k}_t = s_K k_t^{\alpha} h_t^{\beta} - [\delta + g_L + \mu\widetilde{n}(k_t, h_t; \theta)(a_t^{-1} - 1)]k_t \tag{22}$$

$$\dot{h}_t = s_H k_t^{\alpha} h_t^{\beta} - [\delta + g_L + \mu\widetilde{n}(k_t, h_t; \theta)(a_t^{-1} - 1)]h_t \tag{23}$$

Equations (22) and (23) are identical to the differential equations of neoclassical growth theory with both physical and human capital (Mankiw et al., 1992), except that the rate of technological progress is endogenous. The evolution of the economy is now completely

[18] Howitt (2000) includes a model where the growth rate of the world economy is endogenously determined. I will later make the reasonable assumption that the Nordic countries take this rate as given. Endogenising g_t would then only make the analysis more complicated, without adding new insights.

described by the equations (21), (22) and (23) together with the trajectory of the world rate of technological progress $\{g_t\}_0^\infty$ and the initial values a_0, k_0 and h_0.

Steady-State Analysis

Assume that g_t is constant and consider an economy in steady-state, i.e. $\dot{k}_t = \dot{h}_t = \dot{a}_t = 0$. The steady-state is then, according to (21), (22) and (23) defined by the equations

$$k^* = [\frac{s_K^{1-\beta} s_H^{\beta}}{\delta + g_L + g}]^{\frac{1}{1-\alpha-\beta}} \tag{24}$$

$$h^* = [\frac{s_K^{\alpha} s_H^{1-\alpha}}{\delta + g_L + g}]^{\frac{1}{1-\alpha-\beta}} \tag{25}$$

$$a^* = \frac{\mu\widetilde{n}(k^*, h^*; \theta)}{g + \mu\widetilde{n}(k^*, h^*; \theta)} \tag{26}$$

From (9) we see that in steady-state output per effective worker is constant and we can derive steady-state output per worker

$$Y_t/L_t = a^*(k^*)^\alpha(h^*)^\beta A_t^{\max} \tag{27}$$

From the above equations it is straight-forward to show that a country's income per worker Y_t/L_t *at a given date* depends positively on its investment rates s_K and s_H, the productivity on its R&D μ and its subsidy rate ψ[19]. It depends negatively on the world rate of technological progress g and the growth rate of the country's population g_L. As can be seen from equation (27), in this model, the steady-state growth rate of output per worker is equal to the world rate of technological progress as in the neoclassical model. However, this model provides a more complete account of cross-country differences in output per worker. Differences in output per worker are not only caused by differences in physical and human capital per effective worker, but also by differences in relative productivity levels.

By substituting from (24) and (25) into (26), we can write a^* as a function of s_K, s_H, θ and g

$$a^* = \widetilde{a}(s_K, s_H, \theta, g) \tag{28}$$

[19]Segerstrom (2000) shows that the impact of the R&D subsidy rate on the level and the long run growth rate of income per worker can as well be negative as positive by allowing for subsidizing of both vertical and horizontal R&D.

and by substituting from (24), (25) and (28) into (27) and taking logs, we arrive at the same steady-state equation as given in Howitt (2000)

$$\begin{aligned}\ln(Y_t/L_t) \quad = \quad & \frac{\alpha}{1-\alpha-\beta}(\ln s_K - \ln(\delta + g_L + g)) \\ & + \frac{\beta}{1-\alpha-\beta}(\ln s_H - \ln(\delta + g_L + g)) \\ & + \ln A_t^{\max} + \ln \widetilde{a}(s_K, s_H, \theta, g)\end{aligned} \tag{29}$$

The steady-state equation can be expressed in an alternative way by combining equations (25) and (29). This yields an equation for output per worker as a function of the *level* of human capital per worker

$$\begin{aligned}\ln(Y_t/L_t) \quad = \quad & \frac{\alpha}{1-\alpha}(\ln s_K - \ln(\delta + g_L + g)) + \frac{\beta}{1-\alpha}\ln(\frac{H}{L}) \\ & + \frac{1-\alpha-\beta}{1-\alpha}(\ln A_t^{\max} + \ln \widetilde{a}(s_K, s_H, \theta, g))\end{aligned} \tag{30}$$

These equations are almost identical to the equations estimated by Mankiw et al. (1992) except that (29) and (30) include the relative productivity level. The model by Mankiw et al. (1992) had great success in explaining cross-country differences in the level of output per worker in several samples of countries.

2.3 Specification

The natural question to consider now is whether the data support this model's predictions concerning the determinants of standards of living and if it can explain the differences in growth performance between the Nordic countries. In particular, I will focus on the model's predictions concerning the impact of differences in the levels of human capital and R&D intensities on the Nordic countries' per capita GDP growth. Hopefully, the model will be suitable as a framework for a quantitative analysis of the importance of R&D and education on economic growth, but later I will include in my analysis results and findings taken from the vast literature on education, R&D and growth that the model does not strictly imply, relaxing some of its assumptions.

The empirical specification is based on the steady-state equation (30), since the available data on human capital correspond more closely to the level of human capital than to the rate of accumulation as is explained in Appendix D.

As in Howitt (2000) I will take a loglinear approximation of $a^* = \mu\widetilde{n}(k^*, h^*; \theta)/(g + \mu\widetilde{n}(k^*, h^*; \theta))$, (recalling that $n_t = (\frac{R\&D_t}{N_t})/A_t^{\max}$ and g is a constant)

$$\begin{aligned} \ln a^* &= \ln \widetilde{a}(s_K, s_H, \theta, g) \approx C_0 + \kappa \ln \widetilde{n}(k^*, h^*; \theta) \\ &= C_0 + \kappa(\ln(R\&D/Y)^* + \ln(\widehat{Y/L}) + \ln \ell - \ln(\widehat{A^{\max}})) \end{aligned} \tag{31}$$

where C_0 is a constant and $(R\&D/Y\ )^*$ is the steady-state R&D intensity. A hat denotes a variable that grows at a constant rate in steady state. We see that $\ln a^*$ is constant in steady-state, since Y/L and $A^{\max}$ then grow at the same rate g.

I will as an approximation assume that log output per "effective" worker at date $t+s$, $y(t+s)$, is a weighted average of log output per "effective" worker at date t, $y(t)$, ("initial" log output per "effective" worker) and of steady-state log output per "effective" worker, y^*

$$\ln y(t+s) = (1 - e^{-\eta s}) \ln y^* + e^{-\eta s} \ln y(t) \tag{32}$$

The weights depend on t and on the convergence rate η[20]. I will also assume that η is the convergence rate for $a(t)$

$$\ln a(t+s) = (1 - e^{-\eta s}) \ln a^* + e^{-\eta s} \ln a(t) \tag{33}$$

This must be seen as a simplification only, the two convergence rates could very well differ. From (20), (30), (32) and (33) we then get

$$\begin{aligned} \ln(Y(t+s)/L(t+s)) &= (1 - e^{-\eta s})\{\frac{\alpha}{1-\alpha}(\ln s_K - \ln(\delta + g_L + g)) \\ &+\frac{\beta}{1-\alpha}\ln(H/L)^* + \kappa \ln(R\&D/Y)^* \\ &+\kappa \ln g_L - \kappa \ln \varepsilon + C_0 + \kappa(\ln(\widehat{Y/L}) - \ln(\widehat{A^{\max}})) \\ &+\frac{e^{-\eta s}}{(1 - e^{-\eta s})}((\ln(Y(t)/L(t)) - \ln A_t^{\max})\} + \ln A_{t+s}^{\max} \end{aligned} \tag{34}$$

where $(H/L)^*$ is the steady-state level of human capital per worker.

There is no strong reason to expect depreciation rates to vary greatly across countries, nor are there any data available to estimate country-specific depreciation rates (Mankiw

[20] The convergence rate implied by our model is not equal to the standard neoclassical convergence rate which is $(g_L + g + \delta)(1 - \alpha)$ (Mankiw, 1995) when only physical capital is allowed to accumulate over time.

et al., 1992), thus δ is assumed as in most of the growth literature to be identical in all countries. $A_t^{\max}$ is common for all countries and g is per definition not country-specific. δ and g are also assumed constant over time. The assumption made earlier that all countries share the same production function is standard (making α and β identical in all countries) and even though they are quite strong assumptions, I will assume that κ, C_0, η and ε are not country-specific parameters. The two former predicted by the model to be influenced by ψ and μ which, in addition to ε and η, are parameters that may very well differ from country to country. Hence, these assumptions must be seen as simplifications only.

I will assume that the level of output, $Y_j(t{+}s)$, and the number of workers, $L_j(t{+}s)$, are specific to country j at any date $t+s$. At the same date I will as an approximation of the country specific steady-state variables use the average of the variables over the past s years. The notation I will use on these approximations is; R&D intensity, $(\overline{R\&D/Y})_j(t,s)$, the growth rate of the population, $\overline{g_{L_j}}(t,s)$, the investment rate of physical capital, $\overline{s_{K_j}}(t,s)$, and the level of human capital per worker, $(\overline{H/L})_j(t,s)$.

By taking these assumption into account and by using that at a given date t, $A_t^{\max} = A_0^{\max}e^{gt}$, where $A_0^{\max}$ is an "initial leading-edge technology parameter", we get

$$\begin{aligned}
\ln(Y_j(t+s)/L_j(t+s)) \;=\; & (1-e^{-\eta s})\{C_1 \\
& +\frac{\alpha}{1-\alpha}(\ln \overline{s_{K_j}}(t,s) - \ln(\delta + \overline{g_{L_j}}(t,s) + g)) \\
& +\frac{\beta}{1-\alpha}\ln(\overline{H/L})_j(t,s) + \kappa(\ln(\overline{R\&D/Y})_j(t,s) + \ln \overline{g_{L_j}}(t,s)) \\
& +\frac{e^{-\eta s}}{(1-e^{-\eta s})}\ln(Y_j(t)/L_j(t)) \\
& +\kappa(\ln(\widehat{Y/L}) - \ln(\widehat{A^{\max}})) + gt\}
\end{aligned} \tag{35}$$

where $C_1 = \kappa \ln \varepsilon + C_0 + \ln A_0^{\max} + gs/(1-e^{-\eta s})$.

The term $\ln(\widehat{Y/L}) - \ln(\widehat{A^{\max}})$ in (35) is constant over time, but country specific, since the steady-state value of Y/L at date t may differ from country to country. The term gt in (35) is not country specific, but changing over time. I will, however, assume that a constant and a disturbance term will pick up this variation[21], arriving at the following empirical specification

$$\begin{aligned}
\ln(Y_j(t+s)/L_j(t+s)) = {} & constant \qquad (36)\\
& +(1-e^{-\eta s})\frac{\alpha}{1-\alpha}(\ln \overline{s_{K_j}}(t,s) - \ln(\delta + \overline{g_{L_j}}(t,s) + g))\\
& +\frac{\beta}{1-\alpha}(1-e^{-\eta s})\ln(\overline{H/L})_j(t,s)\\
& +\kappa(1-e^{-\eta s})(\ln(\overline{R\&D/Y})_j(t,s) + \ln \overline{g_{L_j}}(t,s))\\
& +e^{-\eta s}\ln(Y_j(t)/L_j(t)) + u_j(t+s)
\end{aligned}$$

This may also be interpreted as an equation determining productivity growth: subtracting $\ln(Y_j(t)/L_j(t))$ from both sides, we obtain

$$\begin{aligned}
\ln\frac{Y_j(t+s)/L_j(t+s)}{Y_j(t)/L_j(t)} = {} & constant \qquad (37)\\
& +(1-e^{-\eta s})\frac{\alpha}{1-\alpha}(\ln \overline{s_{K_j}}(t,s) - \ln(\delta + \overline{g_{L_j}}(t,s) + g))\\
& +\frac{\beta}{1-\alpha}(1-e^{-\eta s})\ln(\overline{H/L})_j(t,s)\\
& +\kappa(1-e^{-\eta s})(\ln(\overline{R\&D/Y})_j(t,s) + \ln \overline{g_{L_j}}(t,s))\\
& -(1-e^{-\eta s})\ln(Y_j(t)/L_j(t)) + u_j(t+s)
\end{aligned}$$

The parameters to be estimated are $\eta, \alpha, \beta, \kappa$ and the constant. This specification is almost identical to one of the specifications presented in Lichtenberg (1993), where a neoclassical model enlarged to include both R&D and human capital is used as a framework. However, using the accumulation rate of human capital instead of the level of human capital. The regression run by Lichtenberg (1993) was a success when the data sets in Mankiw et al. (1992) were used, explaining even more of the cross-country differences.

[21] Later, I will, when running the regressions, add time and country dummies to investigate if this simplification is crucial for my findings.

3 Data Material

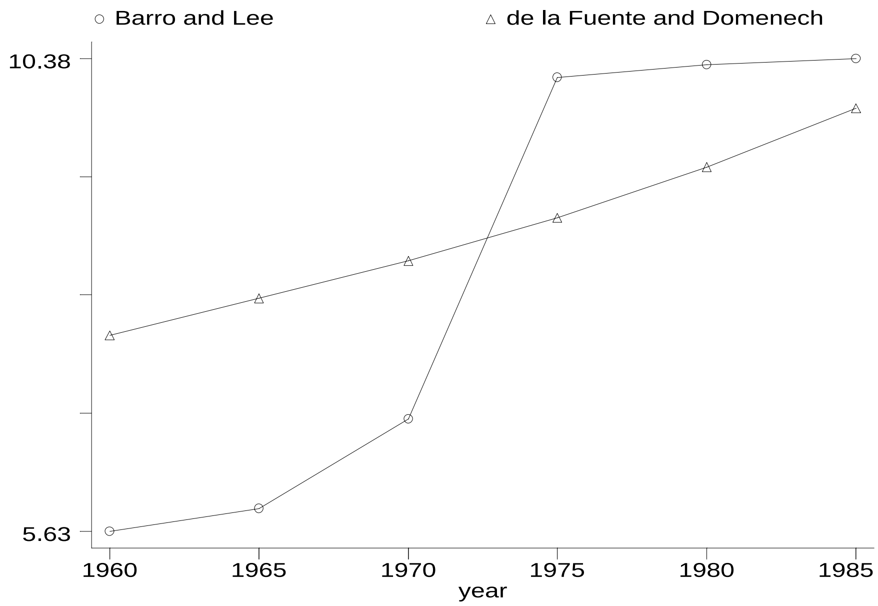
The theoretical structure, taken from Howitt (2000), outlined in 2.2, gives a fairly detailed description of the link between resources devoted to R&D and education, and the growth of output per worker. It provides us with a framework for discussing this link in the Nordic countries. The theoretical structure looks promising, since the empirical specification derived in 2.3 is almost identical to a specification presented by Lichtenberg (1993) which has been successful in explaining cross-country differences in per capita GDP growth in several samples of countries. However, before investigating whether this framework successfully explains the cross-country differences among the Nordic countries, we need to discuss what kind of data to use. In particular human capital and R&D are difficult to measure. A more thorough discussion of how to measure human capital, R&D and GDP per capita are given in Appendix B.

Measuring human capital involves several problems and at least two deserve a closer look. First, what should be included in a measure of human capital? Health, experience, formal education, acquisition of knowledge outside formal schooling like learning by doing and on-the-job training are all examples of different forms of human capital investments. Some of the factors above are, if not impossible, very hard to measure. Hence, as used in several cross-country empirical investigations, I will use formal education as an approximation of human capital. Topel (1999) and Barro (1997) include several of the other forms of human capital in their empirical investigations and both point out formal education as the most important form of human capital in the explanation of economic growth, giving support to our simplification.

How to measure the educational level of a country's population is not straight forward. In particular, it is difficult to control for changes over time and differences across countries in the quality and efficiency of educational systems. Average years of schooling of total population is a measure that fails to control for these factors. Several authors have presented indexes that do not share this unfortunate feature. For instance, Mulligan and Sala-i-Martin (2000) suggest how to construct a measure that clearly is superior to average years of schooling as an approximation of human capital. However, no such measure is constructed in a consistent way for the countries and period of time under consideration. Thus I end up using average years of schooling, bearing in mind the uncertainty of this measure when interpreting the results.

Barro and Lee's (1996) data set is perhaps the most frequently used source by economists trying to explain cross-country variation in growth performance by differences in educational attainments. Although for a long time probably the best one available, it displays rather suspicious features in terms of both the ordering of countries and the evolution of schooling levels over time. de la Fuente and Doménech (2000) have constructed a revised version of Barro and Lee's data set, trying to improve the quality of data by using previously unexploited OECD and national sources. The data set by de la Fuente and Doménech certainly looks more reliable as can be seen from Figure 1, at least when it comes to the evolution of average years of schooling in Norway. Barro and Lee's data set implies an increase in average years of schooling from 6.76 in 1970 to 10.19 in 1975. This is obviously far from reality, whereas de la Fuente and Doménech's data set implies a smoother and more plausible evolution of this measure.

Figure 1: Average years of schooling of Norway's total population, 1960-1985.



By doing the same comparison between the two sets of data with the other Nordic countries, one finds differences, but they are relatively minor. Since the data set by de la Fuente and Doménech is constructed by using previously unexploited information and clearly has a more accurate description of the evolution of average years of schooling in Norway than Barro and Lee's, data on this variable will be taken from de la Fuente and

Doménech's set.

Before deciding which data to use on the ratio of R&D expenditure to output, the R&D investment rate, one has to define what kind of R&D one is going to include in the analysis. For instance, should both "government-funded" and "privately-funded" R&D be measured? Some of these different kinds of R&D are difficult to untangle. The lack of data for the composition of R&D expenditure in the 1970s prohibits me from distinguishing between different forms of R&D, so I use a broad definition of R&D. However, bear in mind that there can be substantial differences in the composition of total R&D expenditure between the different countries when interpreting the results. In 1995, the composition of R&D expenditure did not, with the exception of Sweden, differ substantially across the Nordic countries, as Table I indicates.

R&D as a percentage of GDP is taken from *Nordisk statistisk årbok 1999* extended to include observations in 1970, 1975 and 1980 by using growth rates from *UNESCO Statistical yearbook*[22] 1970-1985, resulting in observations in the period 1970-1995[23]. There are no available observations prior to 1970.

Table I: Percentage of total R&D expenditure performed in different sectors, 1995[24].

	Private sector	Public sector	Universities
Norway	57	18	26
Sweden	74	4	22
Denmark	58	17	25
Finland	64	17	20

In the theoretical model it is assumed that the growth rate of GDP per capita and GDP per worker are equal. In reality, this is not the case. In general, the volatility of GDP per capita is higher than the volatility of GDP per worker. However, since GDP per capita is measured more accurately due to difficulties in measuring the number of workers in a consistent way across countries and since it is available for the period of time under consideration in several sources, I will use GDP per capita in this analysis[25].

[22] This source reports R&D expenditure as a percentage of GNI.

[23] These are presented in Figure 4.

[24] Data downloaded July 2001 from The Research Council of Norway's homepage: http://www.forskningsradet.no/bibliotek/statistikk/indikator_1999/tabelldel/a-5-11.html

[25] I have also used GDP per worker, but this did not qualitatively alter the results.

When comparing the level of GDP per capita between countries, one have to measure GDP per capita in the same unit. Usually, this involves using purchasing power parities (PPP). Different PPPs and different methods of handling what is known as the "inconsistency problem between national accounts and successive benchmark estimates used to construct PPPs"[26] result in an ordering of countries and growth rates of GDP per capita that vary from data set to data set. Moen (2001) compares the evolution of GDP per capita in the Nordic countries using data from Summers and Heston (1991) and Maddison (1995) and finds major differences between the two sets of data. Moen (2001) suggests that Maddison (1995) is appropriate to use in cross-country per capita GDP growth comparisons, since the implied growth rates from this source are consistent with National accounts. Data are taken from this well known set, extended to include observations in 1995 by using growth rates from *Nordisk statistisk årbok 1999*

Investment rates of physical capital are taken from the data set by Summers and Heston (1991), extended to include observations in 1995 by using growth rates from *Nordisk statistisk årbok 1999.* The population growth rates are taken from Maddison (1995), extended to include observations in 1995 by using growth rates from *Nordisk statistisk årbok 1999.* Differences in these measures between sources are minor. Hence, for investment rates of physical capital and population growth rates, the choice of data sets is based on the degree of availability only.

I will assume the rate of depreciation, δ, to be 0.03 and the world rate of technological progress, g, to be 0.02. This is standard in most of the empirical investigations of growth[27]. However, some investigations, like Perez-Sebastian (2000), assume a lower depreciation rate. A reasonable approximation of g is the growth rate of income per capita in the US, since the US practically are the forefront of technology. Anyhow, setting $g = 0.02$ is not a crucial assumption, since our results do not change qualtitatively when using other reasonable magnitudes of this parameter.

[26] This problem is discussed in Moen (2001).

[27] e.g. Howitt (2000), Lichtenberg (1993), Mankiw et al.(1992).

4 A Comparative View

Below are GDP per capita, educational attainment and resources devoted to R&D in the Nordic countries briefly discussed. Focus is on the development of these factors over time and in particular cross-country differences are emphasized.

4.1 GDP per capita

Even though GDP per capita leaves out several important factors influencing peoples welfare[28] and there are substantial measurement problems[29], it is the most frequently used measure of a country's standard of living. PPP adjusted GDP per capita in constant 1990 USD for the Nordic countries is presented below in Figure 2.

As we can see, the Nordic countries have experienced a substantial increase in the level of GDP per capita. Norway's level in 1995 is 4.2 times higher than in 1945, making Norway the country with the highest growth rate over this period of time followed by Finland, Denmark and Sweden with a GDP per capita level in 1995 which is respectively 3.6, 3.1 and 2.1 times higher than in 1945.

Over this period of 50 years, the average annual growth of GDP per capita in Norway, Finland, Denmark and Sweden were, respectively, 3.4, 3.2, 2.9 and 2.3 percent. The annual growth rates have been quite stable, but in all the countries the average annual growth rates in the first 25 years of the period are higher than in the last 25 years. This decrease in growth rates is clearly seen from Figure 2.

Figure 2 indicates that unconditional convergence has taken place. This is confirmed in Figure 3, where I find a negative relationship between the growth rate and the average level of GDP per capita[30]. However, the negative relationship is not statistical significant. This finding is mostly due to the high growth of GDP per capita in Norway combined with a relative high average level of GDP per capita. A closer examination reveals that there is stronger evidence in favour of the convergence hypothesis in the period 1945-1970 than in the period 1970-1995.

[28] See Rødseth (1998) for a discussion of important factors not included in GDP and Nordhaus (2000) for suggestions to improve this measure.

[29] See e.g. Boskin (2000) and NOU 1996:4.

[30] Percentage growth rate of GDP per capita from 1945 to 1995 is plotted against the average level of GDP per capita over the same period as suggested in Quah (1993).

Figure 2: GDP per capita, 1945-1995, log scale.

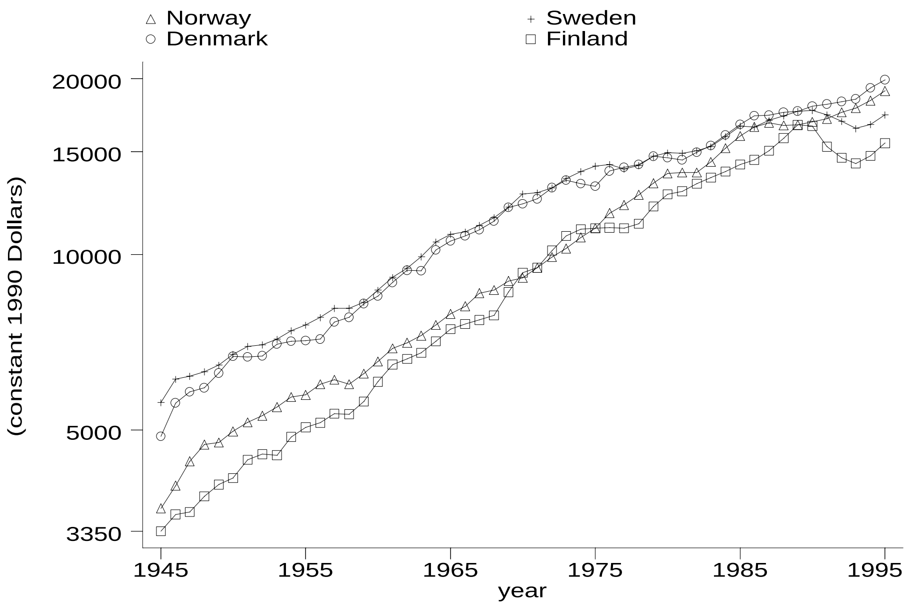
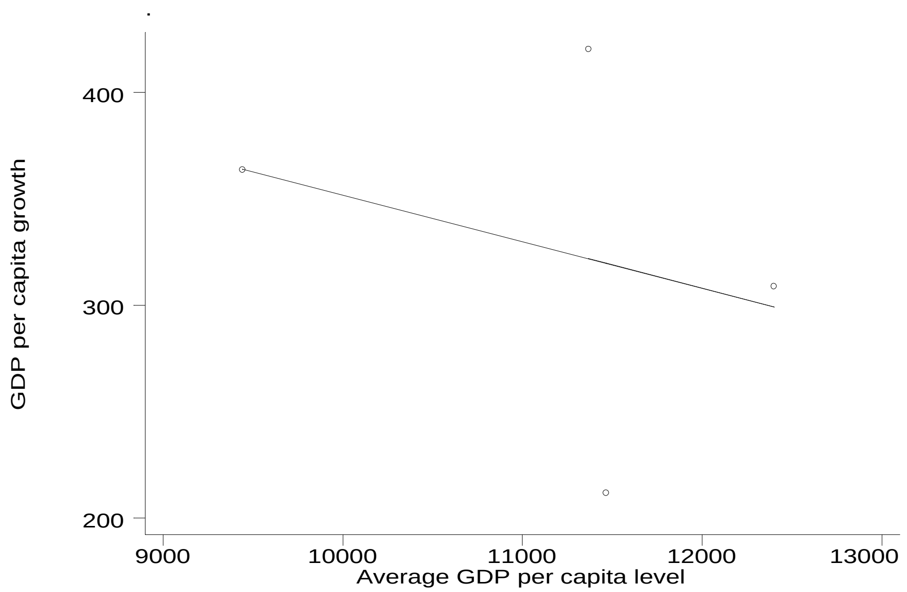


Figure 3: Scatterplot; percentage GDP per capita growth against average level of GDP per capita.



4.2 Education

As shown in Figure 4, in 1995 the differences in average years of schooling between the Nordic countries' population were rather small, all with values between 11 and 12 years. The differences between the countries are substantial for other periods of time, though, since historically, there has been strong cross-country variation in the growth rate of this variable. From 1960 to 1995 the average years of schooling of total population increased by 3.75 and 3.10 years in Finland and Sweden, respectively. Over the same period of time, Norway and Denmark experienced a slower growth. Average years of schooling only increased by 1.88 and 1.09, respectively. Focusing on one country at the time, we see that the annual growth rate of this variable has been stable.

Figure 4: Average years of schooling of total population, 1960-1995, log scale.

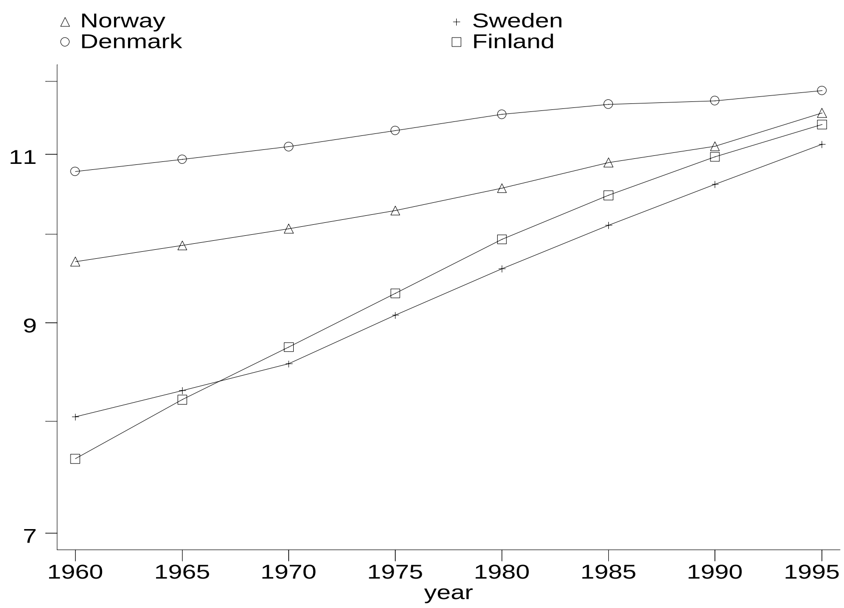


Figure 4 leaves out several important facts about education. Some of the most important ones are the quality of the educational system and the distribution of educational attainment over the population. In particular, these aspects are important when making cross-country comparisons and are discussed in Appendix B.

4.3 R&D

The search for new ideas has intensified in all Nordic' countries. Figure 5 clearly demonstrates the increase in resources devoted to R&D activities. The cross-country differences are large. For instance, in 1995, Sweden used 3.85 percent of their GDP to R&D, whereas Norway used only 1.72 percent. Sweden is by far the country that spends most resources on searching for new ideas. Finland, from only using 0.9 percent of GDP on R&D in 1970, devoted 2.37 percent on such activities in 1995, implying a rapid growth. Norway and Denmark experienced an almost equal development of R&D expenditures over this period of time, both starting at a level of 1 percent of GDP in 1970, slowly growing to a level just under 2 percent in 1995.

Figure 5: R&D expenditure as a percentage of GDP, 1970-1995, log scale.

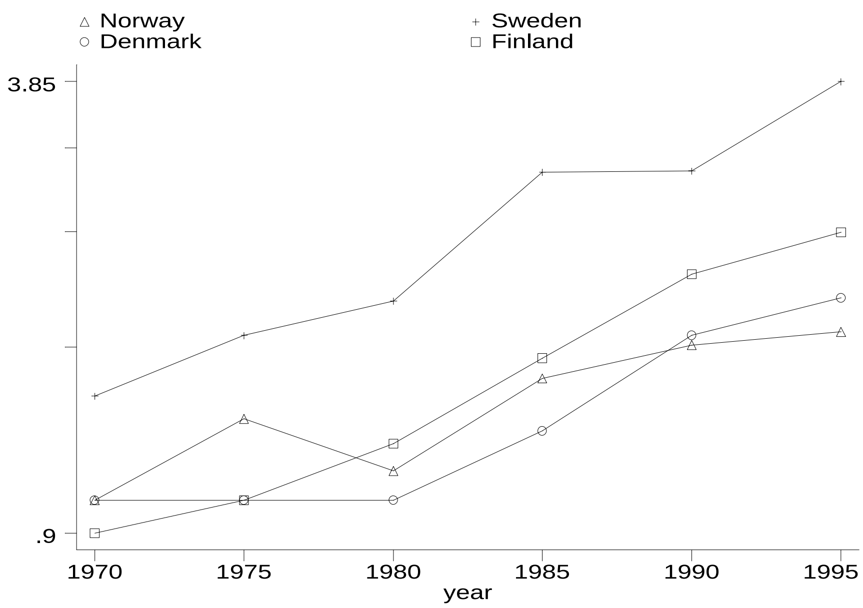


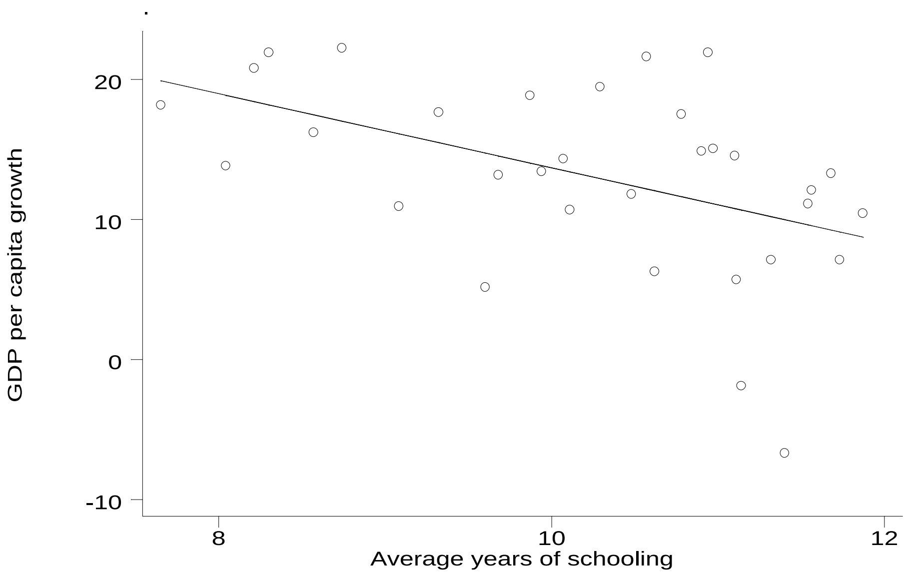
Figure 5 leaves out several important facts about R&D, though. Some of the most important ones are what kind of R&D activities the countries engage in and the quality of the conducted R&D. In particular, these aspects are important when making cross-country comparisons and are discussed in Appendix B.

5 Results[31]

5.1 Preliminary examination

As a preliminary examination of the relationship between educational attainment and growth, and between resources devoted to R&D and growth, Figure 6 and Figure 7 present scatterplots of these variables[32].

Figure 6: Scatterplot; GDP per capita growth against average years of schooling.

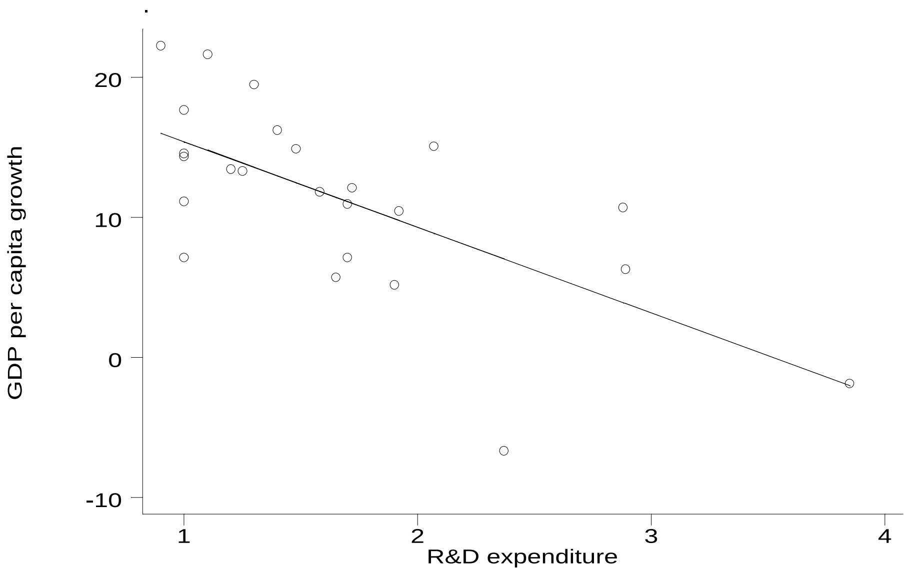


Both average years of schooling and R&D expenditures have a statistical significant negative impact on economic growth in this preliminary examination. However, hardly a surprise, since theses variables have increased steadily over time, whereas the growth rate of GDP per capita has decreased. Since several typical determinants of growth in the literature are highly correlated, trying to explain growth by focusing on one variable at a time is meaningless. In light of the results above, equally meaningless is perhaps leaving out the "initial" level of GDP per capita as an explanatory variable. Thus, little insight is gained from the empirical investigation in Figure 6 and 7, without an apriori opinion on

[31] I use the method of ordinary least squares and STATA 6.0 to run the regressions.

[32] The growth rate of GDP per capita over five-year intervals is plotted against average years of schooling and R&D expenditure as a percentage of GDP in the last year of these intervals. I have used pooled data.

Figure 7: Scatterplot; GDP per capita growth against R&D expenditure.



what causes economic growth and through which routes these determinants of growth are working. Therefore, returning to the framework established in section 2[33]. However, as will be shown, the results from this preliminary examination are not altered substantially.

5.2 Estimation

The theoretical model outlined above emphasizes the investment rate of physical capital, the growth rate of the population, the level of the human capital stock, the R&D intensity and the initial output per capita as key determinants of economic growth. In addition to predicting the signs of the coefficients on the different factors, it also says something about their magnitudes, e.g. the coefficients on $\ln \overline{s_K}$ and $\ln(\delta + \overline{g_L} + g)$ are equal in magnitude, but opposite in sign according to equation (37), restated below, giving us another way to investigate if data support the model. Knowing that α, the physical capital's share of income, should be around $\frac{1}{3}$, yet another way to investigate if the model fits data, is to discuss if the implied magnitude of α (and the implied magnitude of the other parameters) is plausible.

Mankiw et al. (1992) used a sample period of 25 years, that is s=25 in equation (37).

[33] See McGratten and Schmitz (1999) for a discussion on the importance of developing such a framework to explain cross-country growth differences.

However, they included a large number of countries in their samples and did not exploit the time dimension in their data set. Only focusing on four countries, this is necessary to get enough observations. Thus, I will use pooled data at five-year intervals, s=5, as in e.g. de la Fuente and Doménech (2001). However, later I will evaluate the robustness of the results to changes in the length of the interval by letting s change to 10 and 15[34].

$$\begin{aligned}\ln \frac{Y_j(t+s)/L_j(t+s)}{Y_j(t)/L_j(t)} &= constant \\ &+(1-e^{-\eta s})\frac{\alpha}{1-\alpha}(\ln \overline{s_{K_j}}(t,s) - \ln(\delta + \overline{g_{L_j}}(t,s) + g)) \\ &+\frac{\beta}{1-\alpha}(1-e^{-\eta s})\ln(\overline{H/L})_j(t,s) \\ &+\kappa(1-e^{-\eta s})(\ln(\overline{R\&D/Y})_j(t,s) + \ln \overline{g_{L_j}}(t,s)) \\ &-(1-e^{-\eta s})\ln(Y_j(t)/L_j(t)) + u_j(t+s)\end{aligned} \tag{37}$$

Pooling

Due to data limitations on R&D expenditures as discussed above, I focus on growth rates covering 5 five-year intervals. Since the population growth rate in Denmark is negative for one of the intervals, this observation must be omitted, resulting in a sample consisting of 19 observations.

Since the model provides us with perhaps a too strict framework, I will estimate equation (37) both with and without imposing the constraints that some of the coefficients on the different factors are equal. Table IIa and IIIa report the results.

[34] See e.g. Andres et al. (1996) for a discussion of the robustness of the results from regressions based on the enlarged Solow model to changes in sample period for the OECD countries.

Table IIa: unrestricted, five-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	3.52	5.22	0.51
$\ln \overline{s_K}$	0.03	0.14	0.83
$\ln(\delta + \overline{g_L} + g)$	-0.82	2.07	0.70
$\ln(\overline{H/L})$	0.15	0.30	0.62
$\ln(\overline{R\&D/Y})$	0.01	0.10	0.92
$\ln \overline{g_L}$	0.02	0.11	0.87
$\ln(Y_0/L_0)$	-0.26	0.26	0.33

Number of observations: 19

R-squared = 0.54

Adj. R-squared = 0.30

Two aspects of the results support our model. First, all the coefficients have the predicted signs. Second, differences in the predicted determinants of economic growth account for more than one half of the sample variation in GDP per capita growth. However, none of the coefficients are significant.

Table IIIa reports the results when the constraints that the coefficients on $\ln \overline{s_K}$ and $\ln(\delta + \overline{g_L} + g)$ are equal in magnitude and opposite in sign and that the coefficients on $\ln(\overline{R\&D/Y})$ and $\ln \overline{g_L}$ are equal in magnitude and have the same sign are imposed. These constraints follow from equation (37).

Table IIIa: restricted, five-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	1.58	1.36	0.27
$\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$	0.05	0.12	0.68
$\ln(\overline{H/L})$	0.07	0.19	0.70
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.02	0.02	0.36
$\ln(Y_0/L_0)$	-0.18	0.14	0.22

Number of observations: 19		
R-squared = 0.53	Implied α: 0.22	Implied η: 0.04
Adj. R-squared = 0.40	Implied β: 0.31	Implied κ: -0.11

All the coefficients but on $\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$ have the predicted signs. Even though most of the t-ratios have increased, still, none of the coefficients are significant. The differences in the predicted determinants of economic growth account for more than one half of the sample variation in GDP per capita growth as in the unrestricted regression, but the adjusted R-squared has increased to 0.40. The implied estimation for α, β and η are plausible[35], but κ should have a positive sign according to theory. Thus, the model is not completely successful, but taking into account the problems of defining and measuring R&D expenditures discussed above, the model's ability to explain the sample variation in GDP growth per capita is perhaps not that bad.

One reason why none of the coefficients in Table IIIa is significant, could be the large number of coefficients to be estimated relative to only 19 observations in the sample. Since we know α is about $\frac{1}{3}$, I fix α to this value, in order to reduce the number of coefficients to be estimated. Table IVa reports the results.

[35] $\alpha = 0.22$ is somewhat below what is usually assumed ($\alpha \approx \frac{1}{3}$), β almost identical to Mankiw et al.'s (1992) preferred estimate of $\frac{1}{3}$ and η somewhat higher than the usually assumed 0.02.

Table IVa: restricted, $\alpha = \frac{1}{3}$, five-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	1.29	0.40	0.01
$\frac{1}{2}(\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)) - \ln(Y_0/L_0)$	0.15	0.05	0.01
$\ln(\overline{H/L})$	0.06	0.17	0.73
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.02	0.02	0.35

Number of observations: 19		
R-squared = 0.53	Fixed α: $\frac{1}{3}$	Implied η: 0.03
Adj. R-squared = 0.43	Implied β: 0.26	Implied κ: -0.13

Fixing α does not substantially alter the results. The adjusted R-squared increases to 0.43, the implied η decreases to the more plausible value 0.03 and one coefficient is now highly significant, the coefficient on $\frac{1}{2}(\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)) - \ln(Y_0/L_0)$. The coefficient on $\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$ is still negative, though, implying a negative κ equal to -0.13 and the implied β decreases to 0.26, which is somewhat below Mankiw et al.'s (1992) preferred estimate of $\frac{1}{3}$.

In deriving the empirical specification (37) we assumed that the variation in the country specific, but time invariant variable $\ln(\widehat{Y/L}) - \ln(\widehat{A^{\max}})$ and in the time varying variable gt were picked up by a constant and a disturbance term in a satisfactory way. If this is not the case, this assumption might bias the results above. To investigate if the results depend sensitively on this assumption, I have included country and time dummies in the regression.

Since 12 coefficients are to be estimated from only 19 observations, it is difficult to draw conclusions from this investigation. However, as the model predicts (assuming g constant) the time dummies are negative and increasing over time when the last year in the sample is used as a reference year. All the country dummies are positive, and in the case of Norway and Denmark significant, when Finland is used as a reference year. This finding can be interpreted as cross-country differences in the term $\ln(\widehat{Y/L}) - \ln(\widehat{A^{\max}})$. The adjusted R-squared increases to 0.48 when the dummy variables are included and the implied $\alpha = 0.36$ is just over what we expect to find if data supports the model.

However, the coefficient on $\ln(\overline{H/L})$ changes sign, resulting in an implied implausible β equal to -1.33 and the coefficient on $\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$ is still negative. These findings question the model's ability to explain cross-country variation in GDP per capita growth and in particular if a higher level of the human capital stock implies a higher growth rate. Perhaps the positive coefficient on $\ln(\overline{H/L})$ in Table IIa, IIIa and IVa only is a result of the omitted variable gt? Since the growth rates of average years of schooling have been quite steady in all the countries, this may very well be the case. As mentioned above, it is impossible to elaborate on these questions, since the number of observations are small compared to the number of coefficients to be estimated. Table Va in Appendix C reports the results of the regression when time and country dummies are included.

By including a 6th observation per country[36], it is possible to estimate or calibrate equation (37) by using only observations from one country at a time. Even though the sample then only consists of 6 observations and there are 5 coefficients to be estimated, it could give some insight into country specific characteristics. Using data from one country at a time gives the same signs on the coefficients as in Table IIa, IIIa and IVa, except when using observations only from Denmark[37], when the coefficient on $\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$ becomes negative. This implies a negative α, which is obviously wrong. By excluding the four observations from Denmark in the above regressions, however, the results in Table IIa, IIIa and IVa are not substantially altered. For the other countries, the implied α is in the interval (0.21,0.42), but the implied β is larger than an implausible 1.4. Due to data limitations it is impossible to add time dummies which, in light of the discussion above, could have resulted in a smaller value of β. The results from the regression, using country specific samples are given in Appendix C.

[36]The 6th observation is the five-year interval 1965-1970 and is not included in the regressions above due to lack of data on R&D expenditures for this period of time. When including this observation, I have assumed that the average R&D expenditure as a percentage of GDP over the five-year interval is equal to the R&D expenditure as a percentage of GDP in 1970.

[37]Since the average yearly population growth is negative in the interval 1980-1985, this observation must be omitted, instead the interval 1960-1965 is added to the sample, assuming that the average R&D expenditure as a percentage of GDP for this interval is equal to the R&D expenditure as a percentage of GDP in 1970.

Robustness - further eplorations

Equation (37) holds for all t and s, raising the question if the estimated parameters above are stable across periods, the choice of t, and stable across the length of intervals, the choice of s. The former question of stability is discussed in Andrés et al. (1996) where the enlarged Solow model is used as a framework for the OECD countries. Using pooled data at five-year intervals, they find that the estimated parameters differ markedly across periods and that their model is less a success in periods of low growth and macroeconomic turbulence. They also conclude that a number of medium term macroeconomic indicators outperform the explanatory power of conventional growth variables. They do not, however, include an in-depth discussion of the stability of the estimated parameters when it comes to the choice of interval length. Seen in light of their conclusion concerning the impact of medium term macroeconomic indicators on economic growth, this would have been an interesting stability analysis. In addition, it would have been interesting to explore how the explanatory power of these indicators varies with the length of the chosen time interval.

Andrés et al.'s (1996) findings suggest that medium term macroeconomic indicators could have a strong influence on our results when using five-year intervals. By increasing the time interval, the relative importance of such medium term macroeconomic turbulence, which our model is not designed to handle, is expected to decrease, perhaps increasing the explanatory power of the model's predicted determinants of growth. Thus, a stability analysis of the estimated parameters when it comes to the choice of interval length is conducted below. As it has been mentioned before, the choice of interval length varies greatly in the literature, making the analysis even more interesting.

When estimating equation (37), using 10-year and 15-year intervals, I find that the coefficients are unstable. The coefficient on $\ln(\overline{H/L})$ is negative when using 10-year intervals whereas the coefficient on $\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$ is negative when using 15-year intervals, implying an implausible value of, respectively, β and α. However, the sign on the coefficients on $\ln(Y_0/L_0)$ and $\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$ is negative no matter what sample being used. Table IIIb and IIIc in Appendix C present the results of this estimation, when using, respectively, 10-year and 15-year intervals. The two tables are comparable to Table IIIa[38]. When using the 10- and 15-year intervals when running the other type of regressions above, e.g. by fixing $\alpha = \frac{1}{3}$, the results still differ substantially between the three samples. The results of these regressions are also given in Appendix C.

Instead of using GDP per capita from Maddison (1992) as the dependent variable, I have used both GDP per capita and per worker taken from the *Penn World Tables 5.6*. The results do not change substantially, though.

Since I have used average years of schooling as an approximation of the human capital stock, a perhaps better way to model human capital, which is consistent with the large literature on schooling and wages following Mincer (1974), would be to let[39]

$$(H/L)_t = e^{\psi S_t} \ , \quad \psi > 0 \tag{38}$$

where ψ is the marginal increase in productivity of one extra year of schooling and S the average years of schooling. By substituting (38) into the empirical specification, equation (37), we see that the average years of schooling enters the growth equation linearly. The results above do not change substantially, though, when running the regressions, letting ψ be five percent[40].

Finally, one should perhaps exclude the investments in the Norwegian oil sector and its contribution to GDP, since our model is designed to explain growth in "value added" GDP only. Perhaps the inconsistency between our model's prediction and our empirical findings is due to the high growth rates of Norway caused by extraction of natural resources[41]?

[38] The sample period is now 1965-1995, even though data on R&D expenditure is very limited in the 1960s, to increase the number of observations. There are 12 and 8 observations in the samples when using respectively 10-year and 15-year intervals. Since the sample period was 1970-1995 when using five-year intervals, one will by comparing Table IIIa with Table IIIb and IIIc also include elements of a stability analysis across periods. This problem also arises since we had to remove one observation from Denmark, when using five-year intervals due to negative population growth rate. Now the average population growth rate is positive over all intervals. Differences between Table IIIb and IIIc arise from differences in interval length only, though.

[39] This is suggested by Krueger and Lindahl (1999) and used in e.g. Jones (2000).

[40] This parameter is neither constant over time nor across countries. See Appenix B for a more detailed discussion.

[41] In general, it is not obvious that a country with great natural resource wealth grows faster than a resource-poor country, in fact, Sachs and Warner (2001) show that the tendency is the other way around. However, Klette (2000) explains a large part of the strong growth in Norway after 1970 with the extraction of oil.

Effort have not been taken to find "non-oil" data for Norway. However, by omitting observations from Norway in our samples, the sign on the coefficients on the R&D and human capital variables do not change.

It is inappropriate to conclude that our model is successful just because the regressions above can explain a high fraction of the variation in GDP per capita growth, since the estimates imply a negative coefficient on $\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$. In addition, the signs on the coefficients on $\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$ and $\ln(\overline{H/L})$ and the magnitude of the estimated parameters are not robust to changes in the length of the time interval, η being the most stable one ranging from 0.03 to 0.07 in Table IIIa, IIIb and IIIc. This throws more doubt on the model's ability to explain cross-country differences. These unpredicted results could stem from poor data quality, in particular on R&D expenditure and on the level of the human capital stock.

6 Conclusion

This paper presents a Schumpeterian growth model which predicts, in addition to standard Solow-type factors, a country's stock of human capital and its resources devoted to R&D as determinants of the country's per capita GDP growth. The model is used as a framework for an empirical investigation of the Nordic countries' growth performance.

There are in particular three striking patterns of the Nordic economies that have strong influence on my empirical findings. First, Sweden has devoted a large share of GDP on R&D activities, far more than any other Nordic country, but has experienced the slowest growth. This is one reason why I find a significant *negative* relationship between R&D expenditure and economic growth. Henrekson, Jonung and Stymne (1995) explain the combination of high R&D expenditure and low growth in Sweden by high implementation costs of new inventions. Due to high implementation costs in Sweden, Swedish enterprises do not tend to exploit their inventions domestically, but in fact have an exceptional high net exports of licences. A consequence of this transfer of licences may be a reduced spillover rate, resulting in a lower growth rate than one could expect from the level of R&D expenditure. A cross-country examination of implementation costs of new inventions or the fraction of licences which is exported could be a subject of further research.

A second striking pattern is Denmark's high educational attainments combined with modest growth. This is one reason why I find no strong evidence in favour of a positive impact of education on economic growth. Historically, Denmark is clearly the Nordic country with the highest average years of schooling, but only Sweden has experienced a slower growth since 1945. Pedersen (1995) reports that a large fraction of the people with theoretical educations in Denmark is employed in the public sector and use this fact to explain the combination of high educational attainments and slow growth. Since there are substantial measurement problems of the public sector's production, in particular the services it offers (Fløttum and Skoglund, 1997), one could question if the contribution to output of highly educated workers employed in the public sector shows up in reported GDP figures in a satisfactory way. The ongoing debate of how to measure public services is thus very interesting from an economic growth theorist's point of view.

Third, since World War II, Norway and Finland have had remarkable high growth rates of GDP per capita. In 1945 these countries were poor in a Nordic perspective, but after experiencing an average annual growth of per capita GDP of, respectively, 3.4 and 3.2 percent over the next 50 years, Finland almost caught up with Sweden and Denmark while Norway even surpassed Sweden in 1995. This is the main reason for finding evidence in favour of the convergence hypothesis.

In light of these empirical findings, I find it legitimate to raise the question if endogenous growth advocates are too optimistic about R&D and human capital[42]. However, it follows from the thorough discussion of the available data that I am in no position to give a definite answer to this question on the basis of the empirical results in this paper. In addition, the samples which I use consist of a small number of observations, making it even more difficult to conclude. However, the positive impact of R&D and education on economic growth which several economic theories imply, do not show up in Nordic data.

To gain deeper insight, further investigations are necessary. Improving the measurement of Nordic human capital and calibrating time series of the composition of the different countries' R&D expenditures are natural aims for further research. An analysis built on the same framework, but that includs more countries in its sample, would also be interesting to conduct. Finally, some of the assumptions made when deriving the empirical specification were rather strict[43]. The implications from the model when relaxing some of these assumptions need a closer look.

[42] See Appendix D for literature on this topic.

[43] For instance, it is assumed that the convergence rate of GDP per effective worker and the convergence rate of a country's relative average productivity parameter to steady-state are equal, see equation (32) and (33).

References

Aghion, P. and P. Howitt (1992): A Model of Growth Through Creative Destruction, *Econometrica,* **60**, 323-351.

Ahmad, S. (1994): Improving inter-spatial and inter-temporal comparability of national accounts, *Journal of Development Economics,* **44**, 53-75.

Andrés, J., R. Doménech and C. Molinas (1996): Macroeconomic performance and convergence in OECD countries, *European Economic Review,* **40**, 1683-1704.

Barro, R.J. (1997): *Determinants of Economic Growth*, Cambridge, Mass.: MIT Press.

Barro, R.J. and X. Sala-i-Martin (1995): *Economic Growth*, New York: McGraw-Hill.

Barro, R.J. and J.W. Lee (1996): International Measures of Schooling Years and Schooling Quality, *American Economic Review,* Papers and Proceedings, **86**, 218-23.

Bhagwati, J. and B. Hansen (1972): Should Growth Rates Be Evaluated at International Prices? in J. Bhagwati and Eckhaus (eds.): *Development and Planning*, London: Allen & Unwin.

Bjorklund, A.(1999): Utbildningspolitik och utbildningens lönsamhet, in L. Calmfors and M. Persson (eds.) *Tillväxt och ekonomisk politik*, Lund: Studentlitteratur.

Boskin, M.J. (2000): Economic Measurement: Progress and Challenges, *American Economic Review,* Papers and Proceedings, **90**, 247-252.

Cozzi, G. (2001): Inventing or Spying? Implications for Growth, *Journal of Economic Growth,* **6**, 55-77.

Daban, T., R. Doménech and C. Molinas (1997): International and Intertemporal Comparisons of Real Product in OECD Countries: a Growth Sensitivity Approach, *Review of Income and Wealth,* **43**, 33-48.

de la Fuente, A. and R. Doménech (2001): Schooling Data, Technological Diffusion and the Neoclassical Model, unpublished, downloaded July 2001 from http://iei.uv.es/~rdomenec.

de la Fuente, A. and R. Doménech (2000): Human Capital in Growth Regressions: How Much Differences Does Data Quality Make? CEPR Discussion Paper No. 2466.

Diewert, W.E. (1993): Test Approaches to International Comparisons, in W.E Diewert and A.O. Nakamura (eds.): *Essays in Index Number Theory,* Vol I, Amsterdam: Elsevier Science Publishers.

Dinopoulos, E. and P. Thompson (1999): Scale effects in Schumpetarian models of economic growth, *Journal of Evolutionary Economics,* **9**, 157-185.

Dinopoulos, E. and P. Thompson (2000): Endogenous growth in a cross-section of countries, *Journal of International Economics,* **51,** 335-362.

Eaton, J. and S. Kortum (2001): Technology, trade, and growth: A unified framework, *European Economic Review,* **45**, 742-755.

Fløttum, E.J. and T. Skoglund (1997): Labour productivity growth in Norway using national accounts data, Statistics Norway Economic Survey Vol 7, 31-37.

Frantzen, D. (2000): R&D, Human Capital and International Technology Spillovers: A Cross-country Analysis, *Scandinavian Journal of Economics,* **102**, 57-75.

Henrekson, M., L. Jonung and J. Stymne (1995): Economic growth and the Swedish model, in N. Crafts and G. Toniolo (eds.): *Economic growth in Europe since 1945,* Cambridge: University Press.

Heston, A. and R. Summers (1991): The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950-1988, *Quarterly Journal of Economics,* **105**, 327-368.

Heston, A. and R. Summers (1993): What Can be Learned from Successive ICP Benchmark Estimates? in A. Szirmai, B. van Ark and D. Pilat (eds.): *Explaining Economic Growth,* Amsterdam: Elsevier Science Publishers.

Heston, A. and R. Summers (1996): International Price and Quantity Comparisons: Potentials and Pitfalls, *American Economic Review,* **86**, 20-24.

Howitt, P. (2000): Endogenous Growth and Cross-Country Income Differences, *American Economic Review,* **90,** 829-846.

Hægeland, T. (1997): Hvor mye bidrar økt utdanning til økonomisk vekst? *Norsk Økonomisk Tidsskrift*, **111**, 93-120.

Hægeland, T. and T.J. Klette (1999): Do Higher Wages Reflect Higher Productivity? Education, Gender and Experience Premiums in a Matched Plant-Worker Data Set, in J.C. Haltiwanger, J. Theeuwes and K.R. Troske (eds.): *The Creation and Analysis of Linked Employer-Employee Data*, Amsterdam: North-Holland.

Hægeland, T., T.J. Klette and K.G. Salvanes (1999): Declining returns to education in Norway? Comparing estimates across cohorts, sectors and over time, *Scandinavian*

Journal of Economics, **101**, 555-576.

Hægeland, T. and J. Møen (2000): Betydningen av høyere utdanning og akademisk forskning for økonomisk vekst - En oversikt over teori og empiri, Statistisk sentralbyrå Rapport 10/2000.

Jones, C.I. (2000): Sources of U.S. Economic Growth in a World of Ideas, downloaded July 2001 from http://elsa.berkeley.edu/~chad/papers.html#sources

Jones, C.I. (1995a): Time Series Tests of Endogenous Growth Models, *Quarterly Journal of Economics,* **110**, 495-525.

Jones, C.I. (1995b): R&D-Based Models of Economic Growth, *Journal of Political Economy,* **103**, 759-784.

Klette, T.J. (2000): Økonomisk Vekst, NOU 2000:21 En strategi for sysselsetting og verdiskaping, Vedlegg 7, Ministry of Government Administration.

Krueger, A.B. and M. Lindahl (1999): Education for Growth in Sweden and the World, NBER Working Paper No. 7190.

Lichtenberg, F.R. (1992): R&D Investment and International Productivity Differences, NBER Working Paper No. 4161.

Maddison, A. (1991): *Dynamic Forces in Capitalist Development – a long-run comparative view,* Oxford: Oxford University Press.

Maddison, A. (1995): *Monitoring the World Economy 1820-1992,* Paris: Organization for Economic Cooperation and Development.

Mankiw, N.G. (1995): The Growth of Nations, *Papers on Economic Activity,* No. 1, 275-310.

Mankiw, N.G., D. Romer and D.N. Weil (1992): A Contribution to the Empirics of Economic Growth, *Quarterly Journal of Economics,* **107**, 407-437.

Martimort, D. and T. Verdier (2000): The Internal Organization of the Firm, Transaction Costs, and Macroeconomic Growth, *Journal of Economic Growth,* **5**, 315-340.

McGratten, E.R and J.A Schmitz, Jr. (1999): Explaining Cross-Country Income Differences, in J.B Taylor and M. Woodford (eds.): *Handbook of Macroeconomics*, Vol 1, Amsterdam: Elsevier Science Publishers.

Mincer, J. (1974): *Schooling, Experience and Earnings,* New York: Columbia University Press.

Moen, O.C. (2001): En sammenligning av ulike datasett, Mimeo Statistics Norway.

Mulligan, C.B and X. Sala-i-Martin (2000): Measuring Aggregate Human Capital, *Journal of Economic Growth,* **5**, 215-252.

Neary, J.P. (2000); True Multilateral Indexes for International Comparisons of Real Income: Theory and Empirics, CEPR Discussion papers series No. 2590

Nordhaus, W.D. (2000): New Directions in Economic Accounting, *American Economic Review,* Papers and Proceedings, **90**, 259-263.

Nordisk statistisk årbok 1999, Copenhagen, Nordiska rådet.

NOU 1996:4 Om grunnlaget for inntektsoppgjørene 1996, Ministry of Government Administration.

Penn World Tables 5.6, downloaded December 2000 from http://pwt.econ.upenn.edu/

Perez-Sebastian, F. (2000): Transitional dynamics in an R&D-based growth model with imitation: Comparing its predictions to the data, *Journal of Monetary Economics,* **45**, 437-461.

Quah, D.T. (1993): Galton's Fallacy and Tests of the Convergence Hypothesis, *Scandinavian Journal of Economics,* **95**, 427-443.

Romer, P.M. (1990): Endogenous Technological Change, *Journal of Political Economy,* **98**, S71-S102.

Romer, P.M. (1994): The Origin of Endogenous Growth, *Journal of Economic Perspectives,* No 8**,** 3-22.

Rødseth, A. (1998): Rike og fattige land: Nasjonalproduktet som mål for inntekt, in A. Rødseth and C. Riis (eds.): *Markeder, Ressurser og Fordeling: Artikler i Anvendt Økonomi,* Oslo: Ad Notam Gyldendal.

Sachs, J.D., A.M. Warner (2001): Natural Resources and Economic Development, The curse of natural resources, *European Economic Review,* **45,** 827-838.

Schumpeter, J.A. (1942): *Capitalism, Socialism and Democracy*, New York: Harper and Brothers.

Segerstrom, P.S. (1998): Endogenous Growth Without Scale Effects, *American Economic Review,* **88**, 1290-1310.

Segerstrom, P.S. (2000): The Long-Run Growth Effects of R&D Subsidies, *Journal of Economic Growth*, **5**, 277-305.

Solow, R.M. (1956): A Contribution to the Theory of Economic Growth, *Quarterly Journal of Economics*, **70**, 65-94.

Storsletten, K. and F. Zilibotti (1999): Utbildning, utbildningspolitik och tillväxt, in L. Calmfors and M. Persson (eds.): *Tillväxt och ekonomisk politik*, Lund: Studentlitteratur.

Spence, M. (1973): Job market signalling, *Quarterly Journal of Economics*, **87**, 355-374.

Swan, T.W. (1956): Economic Growth and Capital Accumulation, *Economic Record*, **32**, 334-361.

The Research Council of Norway's homepage: http://www.forskningsradet.no

Thonstad, K. (1993): Tvilsomme sammenligninger, *Sosialøkonomen*, 47:1, 12-14.

Topel, R. (1999): Labor Markets and Economic Growth, in O. Ashenfelter and D. Card (eds.): *Handbook of Labor Economics*, Vol. 3, Amsterdam: Elsevier Science Publishers.

UNESCO. Statistical yearbook, Paris, 1970-1985.

Wolff, E.N. (2000): Human capital investment and economic growth: exploring the cross-country evidence, *Structural Change and Economic Dynamics*, **11**, 433-472.

A Derivations

This Appendix shows how to derive some of the key results of the model, starting with equation (8):

At a given date t, in the production of the final good, intermediate good i is used such that the marginal product of this good is equal to its price.

$$p_t(i) = A_t(i)\lambda(x_t(i))^{\lambda-1}\ell^{1-\lambda} \tag{39}$$

Each monopolist maximizes revenue less costs. To derive the cost function, one must solve the problem

$$\min_{K,H}\{(r_t+\delta)K_t(i) + (w_t+\delta)H_t(i)\} \text{ subject to } x_t(i) = ((K_t(i))^{\gamma}(H_t(i))^{1-\gamma})/A_t(i) \tag{40}$$

where I have assumed, as in Mankiw et al. (1992), that human capital depreciates with the same rate δ as physical capital. The first order conditions to this problem, where μ is the Lagrangian multiplier, are

$$\begin{array}{lrcl}
\text{(i)} & (\frac{K_t(i)}{H_t(i)})^{\gamma-1} & = & \frac{(r_t+\delta)}{\mu\gamma} \\
\text{(ii)} & (\frac{K_t(i)}{H_t(i)})^{\gamma} & = & \frac{(w_t+\delta)}{\mu(1-\gamma)} \\
\text{(iii)} & x_t(i) & = & ((K_t(i))^{\gamma}(H_t(i))^{1-\gamma})/A_t(i)
\end{array}$$

(i) and (ii) give

$$\frac{K_t(i)}{H_t(i)} = C_1(t) = \frac{K_t}{H_t} \tag{41}$$

where $C_1(t)$ is a constant. All intermediate sectors use physical and human capital in the same proportion. This proportion is equal to the proportion of total supply of physical to human capital. From the first order conditions, one can derive the cost function

$$C(x_t(i)) = C_2(t)A_t(i)x_t(i) \tag{42}$$

where $C_2(t)$ is a constant. All monopolists face the maximization problem

$$\max\{p_t(i)x_t(i) - C(x_t(i))\}$$

inserting from (39) and (42) we get

$$\max A_t(i)(\alpha(x_t(i))^\alpha - C_2(t)x_t(i))$$

with the first order condition

$$x_t(i) = (\frac{C_2(t)}{\alpha^2})^{\frac{1}{\alpha-1}} = x_t$$

Thus, all monopolists choose the same level of production. Using the intermediate good production function, the fact that $(\int A_t(i)di)/N_t = A_t$ and the result from equation (41) in the following way

$$\begin{aligned}
((K_t(i))^\gamma(H_t(i))^{1-\gamma})/A_t(i) &= x_t(i) = x_t \\
(\frac{K_t(i)}{H_t(i)})^\gamma H_t(i) &= A_t(i)x_t \\
(\frac{K_t}{H_t})^\gamma H_t(i) &= A_t(i)x_t \\
(\frac{K_t}{H_t})^\gamma \int H_t(i)di &= x_t \int A_t(i)di \\
K_t^\gamma H_t^{1-\gamma} &= x_t N_t A_t
\end{aligned}$$

equation (8) follows.

B Data

A discussion of how to measure human capital, R&D and GDP per capita follows below and some alternative data sources are suggested. Towards the end, the data which I use are given.

B.1 Measuring human capital, R&D and GDP per capita

As discussed in section 3, formal education is often used in the literature as an approximation of human capital. However, Topel (1999) and Barro (1997) include several of the other forms of human capital in their empirical investigations. They both point out formal education as the most important form of human capital in the explanation of economic growth, giving support to this well used simplification.

Recalling that our steady-state equation could include either the investment rate or stock of human capital, the problem is how to measure society's investment rate or "stock" of education. Both the empirical specification in Lichtenberg (1993) and Mankiw et al. (1992) include the accumulation rate of human capital. In addition to explicit spending on education by different levels of government as well as by families, a large part of investment in education takes place as forgone labour earnings by students (Mankiw et al., 1992), making the investment rate hard to measure. The percentage of the working age population that is in school could then perhaps serve as a reasonable measure of the investment rate in human capital. Mankiw et al. (1992) and Lichtenberg (1993) use a variant of such an approximation, namely the percentage of the working population enrolled in secondary school. Ideally, the measure should have included not only the secondary school enrollment rate, but also the explicit spending and weighted enrollment rates of all levels of education. In short, the enrollment rate of one school should have a weight equal to the wage a typical student of that school would earn if not enrolled. Clearly, a worker with little human capital forgoes a low wage in order to accumulate more human capital, whereas a worker with much human capital forgoes a higher wage. If we measure investment in education in this way, the quality of the education will to some extent be taken into account. With quality I here mean the increase in labour productivity resulting from different kinds of schooling. Bjorklund (1999) concludes that there is a causal connection between higher education and higher productivity and, in Norway's manufacturing sector, Hægeland and Klette (1999) show that there is a close connection between the wage and productivity of a worker. Thus making wages a reasonable measure of the quality of the worker's education. However, this result may not hold in other sectors of the economy or in other countries. Wolff (2000) points out that not all kinds of education increase productivity, but perhaps is more a consumption good than an investment good, and Spence (1974) outlines a signal game which in equilibrium have "over-educated" workers with more education than is optimal from a productivity maximization point of view. Wether or not there is a close connection between wages and productivity in general, is an interesting question, but its answer rather irrelevant for this analysis. We need data on the *expenditure* on education. Then the *value* of education (investment or "stock"), in form of contribution to per capita GDP growth, can be estimated from the model.

Unfortunately, the approximation of the investment rate in human capital suggested above is not derived for the Nordic countries in a consistent way and for the period of time under consideration. Using the same measure as Mankiw et al. (1992) is an alternative, but they only focus on the investments taken place in secondary school. Their measure of human capital investment rates is thus rather poor. First, they leave out investments taken place in primary school, as Krueger and Lindahl (1999) put it; "Focusing only on secondary and higher education is analogous to measuring office capital by only counting the number of stories of buildings above the tenth floor." Second, they leave out expenditures taken place in higher education. Since Storsletten and Zilibotti (1999) point out the number of people with higher education as a key factor in explaining growth, their results could be substantially biased. Thus following Mankiw et al. (1992) is not ideally. In stead I will choose the population's average years of schooling as an approximation of human capital. This is a "stock" variable and explains why the empirical specification in this analysis is based on the steady-state equation including the stock of human capital, not the accumulation rate. One reason for choosing this measure is that differences between countries when it comes to human capital will not be limited to differences in the enrollment rates of secondary school as in Mankiw et al. (1992) and Lichtenberg (1993). Another reason is that since human capital is likely to be measured with error, de la Fuente and Doménech (2001) argue that the levels of human capital will be the most accurate measure of human capital. In addition, Krueger and Lindahl (1999) prefer to measure education as the average years of all schooling and Storsletten and Zilibotti (1999) conclude that average years of schooling is an important factor in determining economic growth.

Even though average years of schooling is chosen as an approximation of human capital, there are several unfortunate properties with this measure, pointed out by Mulligan and Sala-i-Martin (2000). These are related to the problems of measuring the investment rates of human capital discussed above. The most concerning ones are that it assumes that the productivity differentials among workers with different levels of education are proportional to their years of schooling and that one year schooling is assumed to deliver the same increase in skill always and everywhere. For instance, it assumes that one year additional schooling for a worker with 15 years of schooling in one country at a given date results in the same increase in the worker's productivity as if the worker only had one year of schooling and was working in any country at any date. Even though this is obviously far from reality, it could very well serve as a good approximation of the differences among the Nordic countries, if the distribution of the level of education in the population is close to identical in the different countries and at different dates. That is, if the relative wages between workers with different levels of education also are close to identical in the different countries and at different dates. If this is not the case, and wages are a reasonable measure of the quality of education, this approximation will neither reflect differences in the quality of the Nordic countries' educational systems nor possible quality and efficiency improvements in educational systems over time[44]. Hægeland, Klette and Salvanes (1999) find that the earnings dispersion in Norway has been stable, giving support to our simplification. However, Bjorklund (1999) reports that the earnings dispersion in Sweden was smaller in 1981 than in 1968 and that from about 1990 each additional year of schooling raises earnings by just over 4% in Norway, Denmark and Sweden, but by 6% in Finland. This means that in the 1990s the earnings dispersion in Finland was not identical to the other Nordic countries.

Measures have been constructed to deal with the problems described above. Hægeland

[44]See Bjorklund (1999) for a discussion of changes in the quality and effeciency of the Swedish educational system and Storsletten and Zilibotti (1999) for a discussion of the impact of these factors on economic growth.

(1997) has constructed a quality index of labour in Norway, depending on not only the length of the education, but also the quality of the education, assumed reflected through wages, and a number of other characteristics, and Mulligan and Sala-i-Martin (2000) recently constructed a human capital index which in serving as an approximation of the stock of human capital is clearly superior to average years of schooling. However, there are no such data constructed in a consistent way for all the countries and the period of time under consideration. Thus using average years of schooling, but bearing in mind the uncertainty of this measure when interpreting the results.

Before deciding which data to use on the ratio of R&D expenditure to output, the R&D investment rate, one has to define what kind of R&D one is going to include in the analysis. Should both "government-funded" and "privately-funded" R&D be measured, and what about "defense" R&D? Lichtenberg (1993) distinguishes between these different forms of R&D as well as between "fundamental research" and "nonfundamental research" in his empirical investigation. The R&D in the theoretical model presented above takes form as activities trying to improve the quality of existing products to receive monopoly profit. This would be close to "privately-funded nonfundamental research" in Lichtenberg's terminology. However, one of his conclusions is that it seems that "privately-funded" R&D and "fundamental research", not "nonfundamental", are the two forms of R&D that contribute most to output. When in addition some of the different forms of R&D are difficult to untangle, I use, even though the theoretical model suggests otherwise, data on a broad definition of R&D. However, bearing in mind that there can be substantial differences in the composition of total R&D expenditure between the different countries when interpreting the results.

In the theoretical model it is assumed that the growth rate of GDP per capita and GDP per worker are equal. In reality, this is not the case. In general, the volatility of GDP per capita is higher than the volatility of GDP per worker. The latter is then the most suitable measure of the two in this empirical investigation. A perhaps even better measure would be GDP per hour worked, since it is less cyclical and the model is not constructed to explain short term fluctuations. However, measuring the number of workers and hour worked in the Nordic countries in a consistent way involves a higher degree of uncertainty than measuring the countries' population. Thus, GDP per capita is the most accurate measure and since it is available for the period of time under consideration in several sources, it is being used in this analysis.

When comparing the level of GDP per capita between countries, one have to measure GDP per capita in the same unit. Initially it is measured in domestic currencies and the translation to a common currency usually involves using purchasing power parities (PPP), since the exchange rates will give a wrong picture due to differences in countries' overall price levels (Rødseth, 1998). There are, however, several problems constructing PPPs, from collecting price information in different countries to choosing the method to be used in the calculations[45]. Thonstad (1993) shows that these problems sometimes lead to PPPs which, when used, clearly give an unrealistic description of the differences between countries.

This analysis, however, is concerned about not only interspatial, but also intertemporal comparisons of GDP per capita, increasing the complexity of constructing PPPs even further[46]. The main problem is known as the "inconsistency problem between national accounts and successive benchmark estimates used to construct PPPs". Different views of how to solve this problem has resulted in several different sets of data. The data set by Summers and Heston (1991) is perhaps most frequently used in empirical investigations of this kind. However, the implied growth rates of GDP per capita from this set of data are not consistent with the Nordic countries' national accounts data (Moen, 2001). Daban, Doménech and Molinas (1997) constructed a data set that does not share this unfortunate feature as did Maddison (1995). Moen (2001) compares the evolution of GDP per capita in the Nordic countries using data from Summers and Heston (1991) and Maddison (1995) and finds major differences between the two sets of data. In particular, the two sets differ substantially in ordering the Nordic countries' level of GDP per capita, but also the implied growth rates of this variable varies between Summers and Heston (1991) and Maddison (1995). I use Maddison (1995), since Moen (2001) argues that this source is appropriate to use in cross-country investigations of GDP growth, due to consistency between this source's growth rates and the growth rates of National accounts.

[45] See e.g. Diewert (1993) and Neary (2000) for a discussion of different methods.

[46] See e.g. Heston and Summers (1993, 1996), Ahmad (1994) and Bhagwati and Hansen (1972) for contributions to solving the consistensy problems arising when simultaniously doing interspatial and intertemporal comparisons.

B.2 Data set

Country: **Norway**

Year	GDP per capita	I/Y	R&D/Y	Pop. growth	Average years of schooling
1965	7906	31.5	1	0.78	9.78
1970	9122	32.46	1	0.81	9.97
1975	11080	35.2	1.15	0.66	10.18
1980	13755	32.6	1.2	0.42	10.43
1985	15959	28.34	1.29	0.30	10.74
1990	16897	26.28	1.57	0.42	11.01
1995	19070	19.96	1.69	0.53	11.34

Country: **Sweden**

Year	GDP per capita	I/Y	R&D/Y	Pop. growth	Average years of schooling
1965	10815	25.44	1.4	0.67	8.17
1970	12717	26.16	1.4	0.79	8.44
1975	14185	24.98	1.55	0.37	8.83
1980	14935	22.18	1.8	0.28	9.34
1985	16618	19.42	2.39	0.10	9.86
1990	17695	22.58	2.89	0.5	10.37
1995	17362	18.72	3.24	0.73	10.88

Country: **Denmark**

Year	GDP per capita	I/Y	R&D/Y	Pop. growth	Average years of schooling
1965	10552	27.16	1	0.76	10.86
1970	12204	29.24	1	0.71	11.02
1975	13104	29.24	1	0.53	11.21
1980	14645	25.76	1	0.26	11.43
1985	16724	20.18	1.13	-0.04	11.61
1990	17953	22.74	1.48	0.11	11.71
1995	19923	18.28	1.81	0.31	11.80

Country: **Finland**

Year	GDP per capita	I/Y	R&D/Y	Pop. growth	Average years of schooling
1965	7449	36.9	0.9	0.60	7.93
1970	9302	36.62	0.9	0.18	8.48
1975	11098	38.72	0.95	0.45	9.03
1980	12693	32.42	1.1	0.29	9.63
1985	14282	31.62	1.39	0.51	10.21
1990	16604	31.68	1.83	0.34	10.73
1995	15533	22.08	2.22	0.41	11.185

GDP per capita is measured in PPP adjusted constant 1990 USD taken from Maddison (1995) extended by growth rates from *Nordisk statistisk årbok 1999.* I/Y is investment as a percentage of GDP taken from *Penn World Tables 5.6.* extended by using growth rates from *Nordisk statistisk årbok 1999*, R&D/Y is total R&D expenditure as a percentage of GDP taken from *Nordisk statistisk årbok 1999* extended by using growth rates from *UNESCO Statistical yearbook* 1970-1985 and Pop. growth is population growth rate in percent per year taken from Maddison (1995) extended by using growth rates from *Nordisk statistisk årbok 1999*, all averaged for the five-year intervals (e.g. Pop. growth 1975 is the average of the yearly growth rates of the population in the interval 1970-1975). Average years of schooling is the average years of schooling of total population taken from de la Fuente and Doménech (2000), averaged for the five-year intervals.

C Regressions

Using observations only from Norway:

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	-12.88	2.72	0.13
$\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$	0.49	0.13	0.17
$\ln(\overline{H/L})$	12.33	2.29	0.12
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.17	0.04	0.16
$\ln(Y_0/L_0)$	-1.81	0.32	0.11

Number of observations: 6		
R-squared = 0.98	Implied α: 0.21	Implied $\eta \in \emptyset$
Adj. R-squared = 0.91	Implied β: 5.36	Implied κ: -0.09

Using observations only from Sweden:

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	6.26	0.88	0.09
$\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$	0.47	0.09	0.12
$\ln(\overline{H/L})$	2.51	0.44	0.11
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.04	0 .01	0.12
$\ln(Y_0/L_0)$	-1.31	0.20	0.10

Number of observations: 6		
R-squared = 0.99	Implied α: 0.26	Implied $\eta \in \emptyset$
Adj. R-squared = 0.97	Implied β: 1.41	Implied κ: -0.03

Using observations only from Denmark:

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	1.53	0.74	0.68
$\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$	-0.34	0.08	0.15
$\ln(\overline{H/L})$	1.68	2.25	0.59
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.02	0.02	0.52
$\ln(Y_0/L_0)$	-0.53	0.30	0.33

Number of observations: 6		
R-squared = 0.98	Implied $\alpha < 0$	
Adj. R-squared = 0.91		

Using observations only from Finland:

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	0.76	1.26	0.66
$\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$	0.52	0.06	0.07
$\ln(\overline{H/L})$	2.22	0.77	0.21
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.03	0.02	0.46
$\ln(Y_0/L_0)$	-0.71	0.31	0.26

Number of observations: 6		
R-squared = 0.997	Implied α: 0.42	Implied η: 0.24
Adj. R-squared = 0.98	Implied β: 1.80	Implied κ: -0.04

Table IIb: unrestricted, 10-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	11.77	11.66	0.36
$\ln \overline{s_K}$	-0.31	0.44	0.52
$\ln(\delta + \overline{g_L} + g)$	-3.80	4.24	0.41
$\ln(\overline{H/L})$	0.05	0.12	0.92
$\ln(\overline{R\&D/Y})$	-0.16	0.12	0.26
$\ln \overline{g_L}$	0.23	0.28	0.45
$\ln(Y_0/L_0)$	-0.42	0.46	0.40

Number of observations: 12

R-squared = 0.86

Adj. R-squared = 0.69

Table IIc: unrestricted, 15-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	-2.56	30.18	0.95
$\ln \overline{s_K}$	-0.002	0.92	0.999
$\ln(\delta + \overline{g_L} + g)$	3.80	12.61	0.81
$\ln(\overline{H/L})$	-0.05	1.29	0.97
$\ln(\overline{R\&D/Y})$	-0.09	0.32	0.82
$\ln \overline{g_L}$	-0.25	0.71	0.78
$\ln(Y_0/L_0)$	-0.39	1.06	0.78

Number of observations: 8

R-squared = 0.87

Adj. R-squared = 0.21

Table IIIb: restricted, 10-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	2.87	1.73	0.14
$\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$	0.04	0.21	0.85
$\ln(\overline{H/L})$	-0.04	0.24	0.86
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.05	0.03	0.13
$\ln(Y_0/L_0)$	-0.28	0.17	0.15

Number of observations: 12

R-squared = 0.80	Implied α: 0.13	Implied η: 0.03
Adj. R-squared = 0.69	Implied β: -0.88	Implied κ: -0.18

Table IIIc: restricted, 15-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	6.01	2.92	0.13
$\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$	-0.20	0.35	0.61
$\ln(\overline{H/L})$	0.25	0.42	0.60
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.05	0.05	0.37
$\ln(Y_0/L_0)$	-0.64	0.30	0.13

Number of observations: 8

R-squared =0.88	Implied α: -0.45	Implied η: 0.07
Adj. R-squared =0.71	Implied β: 0.57	Implied κ: -0.08

Table IVb: restricted, $\alpha = \frac{1}{3}$, 10-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	2.30	0.45	0.001
$\frac{1}{2}(\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)) - \ln(Y_0/L_0)$	0.22	0.06	0.01
$\ln(\overline{H/L})$	-0.07	0.22	0.74
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.05	0.03	0.11

Number of observations: 12		
R-squared = 0.80	Fixed α: $\frac{1}{3}$	Implied η: 0.02
Adj. R-squared = 0.72	Implied β: -0.21	Implied κ: -0.23

Table IVc: restricted, $\alpha = \frac{1}{3}$, 15-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	3.04	0.77	0.02
$\frac{1}{2}(\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)) - \ln(Y_0/L_0)$	0.34	0.10	0.03
$\ln(\overline{H/L})$	0.06	0.38	0.89
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.06	0.05	0.34

Number of observations: 8		
R-squared = 0.83	Fixed α: $\frac{1}{3}$	Implied η: 0.03
Adj. R-squared = 0.71	Implied β: 0.12	Implied κ: -0.17

Table Va: time and country dummies included, five-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	5.70	3.80	0.18
$\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$	0.23	0.40	0.58
$\ln(\overline{H/L})$	-0.85	0.56	0.17
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.003	0.042	0.94
$\ln(Y_0/L_0)$	-0.41	0.31	0.22
1975	-0.33	0.17	0.09
1980	-0.23	0.14	0.15
1985	-0.12	0.12	0.33
1990	-0.08	0.12	0.51
Norway	0.14	0.06	0.04
Sweden	0.10	0.13	0.49
Denmark	0.23	0.11	0.08

Number of observations:19		
R-squared = 0.80	Implied α: 0.36	Implied η: 0.11
Adj. R-squared = 0.48	Implied β: -1.33	Implied κ: -0.01

Table Vb: time and country dummies included, 10-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	3.33	2.19	0.27
$\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$	0.45	0.22	0.18
$\ln(\overline{H/L})$	-1.30	0.27	0.04
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.01	0.02	0.82
$\ln(Y_0/L_0)$	-0.09	0.16	0.64
1975	-0.19	0.07	0.11
1985	-0.06	0.03	0.18
Norway	0.21	0.03	0.02
Sweden	0.08	0.07	0.39
Denmark	0.31	0.06	0.03

Number of observations: 12

R-squared =0.995	Implied α: 0.83	Implied η: 0.01
Adj. R-squared = 0.97	Implied β: -2.41	Implied κ: -0.11

Table Vc(1): time dummy included, 15-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	10.29	5.77	0.22
$\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)$	-0.47	0.48	0.43
$\ln(\overline{H/L})$	0.27	0.43	0.60
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.05	0.05	0.43
$\ln(Y_0/L_0)$	-1.05	0.57	0.21
1985	-0.13	0.15	0.48

Number of observations: 8

R-squared =0.91	Implied α: -0.81	Implied $\eta \in \emptyset$
Adj. R-squared =0.69	Implied β: 0.47	Implied κ: -0.05

Table Vc(2): restricted, $\alpha = \frac{1}{3}$, country dummies included, 15-year intervals.

Dependent variable: per capita GDP growth

	Coefficients	**Standard errors**	**P>|t|**
constant	2.68	0.07	0.02
$\frac{1}{2}(\ln \overline{s_K} - \ln(\delta + \overline{g_L} + g)) - \ln(Y_0/L_0)$	0.40	0.01	0.02
$\ln(\overline{H/L})$	0.40	0.08	0.12
$\ln(\overline{R\&D/Y}) + \ln \overline{g_L}$	-0.14	0.01	0.03
Norway	0.15	0.004	0.02
Sweden	0.16	0.01	0.05
Denmark	-0.02	0.01	0.25

Number of observations: 8

R-squared = 0.9999	Fixed α: $\frac{1}{3}$	Implied η: 0.03
Adj. R-squared = 0.9993	Implied β: 0.66	Implied κ: -0.35

D Related literature

Several theoretical models identify R&D and human capital as key determinants of economic growth. However, the results from the empirical investigation above throw doubts on these models' conclusions and so do other recent empirical findings e.g. by Jones (1995a). Thus, the natural question to consider is whether endogenous-growth theorists have been overoptimistic about human capital and R&D. This appendix is a survey of some papers concerning this topic. It is in no way exhaustive, or even a modestly complete review of the field, but intended to serve as a background for further research.

Empirical findings. The empirical findings on the link between R&D and economic growth are ambiguous. Jones (1995a) shows that this century's per capita output growth and patenting activities do not seem very responsive to research inputs. The empirical findings in this paper also question the importance of R&D and human capital in explaining growth. However, e.g. Lichtenberg (1993) and Andrés et al. (1996) find that R&D and human capital have substantial explanatory power in cross-country regressions and Frantzen (2000) concludes that domestic R&D has significant influence on growth and that there is clearly a net positive impact on growth of human capital. Andrés et al. (1996) point out that their results are very unstable across subsamples of the OECD countries, though, suggesting that for some groups of countries, R&D and human capital seem to contribute less to economic growth. Thus, differences in samples could be a main reason for the ambiguous empirical findings.

Theory. Over the last recent years, partly as a result of the ambiguous empirical findings, literature has emerged that challenges the endogenous growth models which conclude that economic growth is faster when firms devote more resources to R&D. Jones (1995b) modifies Romer's (1990) model of horizontal innovation to eliminate the "scale effect"[47] that if the level of resources devoted to R&D is doubled, then the per capita growth rate of output should also double, at least in steady-state. In Jones' (1995b) model, even though higher R&D subsidies increases the R&D sector, the long-run rate of growth, which depends on the population growth rate and other exogenous parameters, does not change. Segerstrom (1998) shows that the same results can be derived in a model of vertical innovation.

[47] See Dinopoulos and Thompson (1999) for a discussion of this "scale effect".

In Segerstrom (2000), a Schumpeterian growth model of both horizontal and vertical innovation is presented. Although almost identical to Howitt (2000), his more complete characterization of the long-run growth effects of R&D subsidies results in a steady-state growth rate depending not only on the size of the R&D sector, but also of the distribution of the resources devoted to R&D between the horizontal and vertical innovation sector. Thus, cross-country growth rate differences can occur conditional on the size of the R&D sector and a number of traditional growth determinants, if there are differences in countries' distributions of R&D resources. Segerstrom's (2000) model thus highlights the importance of examine not only a country's total R&D expenditure, but also how the resources devoted to R&D are used in cross-country empirical investigations.

If an economy is correctly described by Cozzi's (2001) Schumpeterian growth model, under some assumptions, an econometrician would find that the growth rate is not affected by increases in the total amount of workers employed in the research sector. According to Cozzi (2001), "spying" could become a problem when a country's population becomes rich in human capital. If the number of R&D workers is large, individuals and firms could have incentives that distort the choice of their R&D production in favour of too much ex ante imitative activity, "spying", than socially optimal. In stead of trying to come up with a major breakthrough idea, R&D workers could find that creating minor variations of radical innovations, which have already been created, but perhaps are not yet applicable, will pay. The incentives to "spy" increases with the number of R&D workers and after a treshold, transforming additional unskilled workers into skilled workers engaging in R&D activities, may have no positive effect on the creation of radical innovations and no positive growth effect. Cozzi (2001) gives some evidence that this previously ignored negative effect of having too many skilled workers are in fact present in advanced economies.

In conclusion, the empirical findings on the impact of R&D and human capital are ambiguous. Thus, recently, several theoretical models where R&D and human capital play a more modest role in explaining economic growth have emerged. Allthough giving new insight, some of these models do not suit themselves well to empirical implementation.

Recent publications in the series Documents

99/14 T.I. Tysse and K. Vaage: Unemployment of Older Norwegian Workers: A Competing Risk Analysis

1999/15 L. Solheim and D. Roll-Hansen: Photocopying in Higher Education

1999/16 F. Brunvoll, E.H. Davila, V. Palm, S. Ribacke, K. Rypdal and L. Tangden: Inventory of Climate Change Indicators for the Nordic Countries.

1999/17 P. Schøning, M.V. Dysterud and E. Engelien: Computerised delimitation of urban settlements: A method based on the use of administrative registers and digital maps.

1999/18 L.-C. Zhang and J. Sexton: ABC of Markov chain Monte Carlo

1999/19 K. Flugsrud, W. Irving and K. Rypdal: Methodological Choice in Inventory Preparation. Suggestions for Good Practice Guidance

1999/20 K. Skrede: Gender Equality in the Labour Market - still a Distant Goal?

1999/21 E. Engelien and P. Schøning: Land Use Statistics for Urban Settlements: Methods based on the use of administrative registers and digital maps

1999/22 R. Kjeldstad: Lone Parents and the "Work Line": Changing Welfare Schemes and Changing Labour Market

2000/1 J.K. Dagsvik: Probabilistic Models for Qualitative Choice Behavior: An Introduction

2000/2 A. Senhaji: "An Evaluation of some Technology Programs executed by the Norwegian Government in the 80's and the 90's

2000/3 K. Rypdal and B. Tornsjø: Environmental Pressure Information System (EPIS) for the Pulp and Paper Industry in Norway

2000/4 K. Rypdal and B. Tornsjø: Chemicals in Environmental Pressure Information System (EPIS)

2000/5 R. Ragnarsøn: The Role of Subcontracting in the Production System

2000/6 K.E. Rosendahl: Industrial Benefits and Costs of Greenhouse Gas Abatement Strategies: Applications of E3ME: Modelling external secondary benefits in the E3ME model

2000/7 G.A. Ellingsen, K.E. Rosendahl and A. Bruvoll: Industrial Benefits and Costs of Greenhouse Gas Abatement Strategies: Applications of E3ME: Inclusion of 6 greenhouse gases and other pollutants into the E3ME model

2000/8 R. Ragnarsøn and L. Solheim: Industry Statistics in Mozambique: Major Findings and Recommendations

2000/9 R. Johannessen: The Consumer Price Index of Mozambique: A Short Term Mission 13-31 March 2000

2000/10 B.K. Wold: Planned Co-operation with Instituto Nacional de Estatística (INE), Mozambique: Report from Short Term Identification Mission 27th March to 3rd April, 2000 Requested by NORAD/Oslo

2000/11 P. Boug: Modelling Energy Demand in Germany: A Cointegration Approach

2000/12 E. Engelien and P. Schøning: Land use statistics for urban settlements

2000/13 M. Rønsen: Impacts on Women's Work and Child Care Choices of Cash-for-Care Programs

2000/14 H.C. Bjørnland: VAR Models in Macroeconomic Research

2000/15 T.L. Andersen: Short-term Statistics in Mozambique: A short-term mission 19 June - 6 July 2000

2000/16 J. Thori Lind: The Use of Household Welfare Functions to Estimate Equivalence Scales

2001/1 T. Bye, R Choudhury, M. Harlarson and P. Hardarson: The ISM model: A CGE model for the Icelandic Economy

2001/2 K.Ø. Sørensen, J.L. Hass, H. Sjølie, P. Tønjum and K. Erlandsen: Norwegian Economic and Environment Accounts (NOREEA) Phase 2

2001/3 G. Haakonsen, K. Rypdal, P. Schøning and S.E. Stave: Towards a National Indicator for Noise Exposure and Annoyance: Part I: Building a Model for Traffic Noise Emissions and Exposure

2001/4 T. Åvitsland: User Costs of Real Capital

2001/5 H.V. Sæbø: Strategic planning and management in Institutio Nacional de Estatística, Mozambique: Short Term Mission Report, November 2 - 9, 2000

2001/6 H.V. Sæbø, J. Byfuglien and R. Johannessen: Quality issues in Statistics Norway

2001/7 J. Byfuglien: Comparability of income data: Project report

2001/8 A.S. Abrahamsen,.M.Q. Andersen and R.Ragnarsøn: Project:Quality of Manufacturing Statistics and Evaluation of Methods for Producing Preliminary and Final Figures. Final Report