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Economic Growth in the U.S. and Europe: The Role of Knowledge, Human Capital and Inventions

by

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Abstract

During the last decade the high unemployment rate in Europe, compared to the U.S., has been attributed to specific labor market problems of the European economy. Recently, U.S. labor market specialists have become skeptical to consider labor market rigidities as the sole cause for the high and persistent unemployment in Europe. It has been argued that Europe, compared to the U.S., has lacked a sufficiently high rate of job creation. This may be due to, as recent empirical studies of the OECD show, large differences in creating new knowledge, human capital and innovations, accompanied by entrepreneurship and new start up firms, between the U.S. and Europe. In order to shed some light on those new forces of economic growth and the creation of jobs we employ a modified version of Romer's (1990) model of endogenous growth. We confront our model with stylized facts employing U.S. and European time series data. We then estimate the parameters with time series data for the U.S. and Germany. We show that, although the long run growth rate may not be affected by scaling up the new forces of economic growth, our model, however, suggests that there are transitory effects arising from the new forces of economic growth which positively affect the labor market. Furthermore, in order to give a qualitative assessment of such transitory effects we present a collection of time series data for some main OECD - countries.

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1 Introduction

In the last decade the high unemployment rate in Europe, compared to the U.S., has been attributed to specific labor market problems in the European economy. A widespread view among academics and politicians was that the high rate of unemployment in Europe has been caused by the labor market itself. It has been maintained that in Europe strong labor unions, strong position of insiders vis-a-vis outsiders on the labor market, restrictions of hiring and firing practices, job protection and generosity of unemployment benefits have caused a persistent high level of unemployment in the E.U.. The flip side of this hypothesis is that conversely labor market flexibility in the U.S. and wage spread has helped to accelerate employment. In particular, it is often maintained that there has been extensive job creation for low income groups. In the last few years, however, many U.S. labor market specialists, see for example Krueger and Pischke (1997), have become skeptical to consider labor market rigidities as the sole cause for the high and persistent rate of unemployment in the E.U.. The volume of the potential labor force in the U.S. that has been integrated into the active workforce has been too large to be explained by labor market flexibilities solely.[1] Conversely Europe, so it is argued by American labor economists, lacked such a large rate of job creation.

Indeed, it is now more and more recognized that in Europe, in contrast to the U.S., there have also been product market rigidities, a lack of new entrepreneurial firms, a much lower growth performance and thus a lower rate of job creation than in the U.S.. The revolution in the information and communication technology has started in Europe with a delay and knowledge based industries have not reached such high growth rates. Furthermore, Europe did not experience such a stock market as well as investment boom as the U.S..[2] As recent empirical studies, e.g. initiated by the OECD economics division[3], indicate it is less the labor market rigidity than the lack of new growth factors that prevented the employment in Europe from rising. In particular, the U.S. leads in creating new knowledge, human capital and innovations accompanied by entrepreneurship and new start-up firms which gave rise to higher employment.

In academic circles, in recent years, it was the 'new growth theory' that has been employed to shed some light on the importance of those factors of growth that where behind recent experiences of economic growth particularly in the U.S.. This paper will attempt to give a quantitative and qualitative assessment of those new forces of

[1]See Krueger and Pischke (1997) and Semmler and Groh (1999).

[2]See Phelps and Zoega (2000).

[3]See e.g. OECD (2000) or Bassanini et al. (2000).

growth. We also attempt to asses whether those forces of growth have been, from early on, stronger in the U.S. than in Europe. We will introduce a formal growth model which is akin to the R&D model of economic growth of the type of Romer (1990) and Grossman and Helpman (1991) and estimate and confront this model for the U.S. and Germany with time series data. We also will give some qualitative interpretation of recent trends in the forces of economic growth.

The 'new' or 'endogenous' growth theory started with the paper by Romer (1986). This model explains persistent economic growth by referring to the role of externalities in economic development. This idea goes back to Arrow (1962) who argued that externalities, arising from learning by doing and knowledge spill-overs, positively affect labor productivity on the aggregate level of an economy. The Lucas version of an endogenous growth model, which goes back to Uzawa (1965), stresses the creation of human capital in its importance for economic growth. Another line of research in the endogenous growth literature was initiated by Romer (1990) and Grossmann and Helpman (1991, ch. 3). Those authors have developed the R&D model of economic growth. In the Romer model the creation of knowledge capital (stock of ideas) is the most important source of growth. In the approach by Grossman and Helpman, a variety of consumer goods enters the households' utility function and spillover effects in the research sector bring sustained per capita growth. Perpetual growth can also arise due to productive public capital or public infrastructural investment. This line of research was initiated by Arrow and Kurz (1970) who, however, only considered exogenous growth models. Barro (1990) demonstrated that this approach may also generate sustained per capita growth in the long run.[4]

Today, numerous empirical tests on growth models exist. Most of those studies are, however, cross-sectional studies. Cross-sectional empirical estimations of recent growth theory can be found either for an extended Solow-approach with human capital or for the endogenous growth theory.[5] We do not survey the cross-sectional studies on endogenous growth theory. The success and failure of those studies is reviewed by Sala-i-Martin (1997) and Durlauf and Quah (1998) sufficiently. Criticism has been raised on the cross-sectional econometric studies. In most studies all countries have identical aggregate production functions and preference parameters. It has been demonstrated that cross-sectional studies, by lumping together countries of different stages of development, may miss thresholds of development (Bernard and Durlauf, 1995). Moreover, the cross-sectional studies rely on imprecise mea-

[4]See also Greiner and Semmler (1999 a,b).

[5]For the former, see for example, Mankiw, Romer and Weil (1992) and for the latter, see Barro and Sala-i-Martin (1996).

sures of the involved economic variables[6] and the results are amazingly non-robust (Sala-i-Martin, 1997). A more explicit assessment of the cross-sectional studies is given in Greiner, Semmler and Gong (2000).

An alternative to cross-sectional studies is the use of time series methods.[7] In fact, in a series of articles and in his book, Jones (1995a,b, 1997) has shifted the attention toward time series predictions of endogenous growth models. Yet, in the time series context another problem arises. Jones has shown that, by confronting endogenous growth models with empirical facts, one is frequently confronted with the prediction that a rise in the level of an economic variable, like an increase in human capital or knowledge capital, implies strong and lasting effects on the growth rate of an economy. In fact, the new forces of growth predict too high growth rates. This property is referred to as a scale effect (Segerstrom, 1998). For example, in the original Romer (1990) model, that takes labor input and human capital as fixed, the growth rate is predicted to increase monotonically with the level of human capital devoted to R&D. Theoretically, those permanent growth effects of human capital, present in the models by Romer (1990), Grossmann and Helpman (1991) or Aghion and Howitt (1992), have been criticized as unreasonable by Lucas (1990) and empirically contested by Jones (1995a,b, 1997). As the stylized facts in sect. 2 show, measures of human capital or research intensity in most advanced countries, have dramatically increased, mostly more than the GNP. Yet, the growth rates of per capita income have roughly remained constant. This gave rise to the question of why the growth rates have not increased more. This indeed is a serious question since one would like to know if a country can expect higher growth rates if it spends more resources for the creation of human capital, the increase of its stock of knowledge or for the increase of stock of public infrastructure.

In this paper we also pursue a time series approach. By estimating the preference and technology parameters of an R&D model of economic growth we want to contribute to the question of which endogenous growth models are compatible with empirical observations for the U.S. and Europe. In the European Union the German economy has the largest population and represents about one third of the total 'Euroland'-GDP. Thus, it can be considered as a potential engine of growth for the European Union.[8] Therefore, we will restrict our time series study to the

[6]See e.g. de la Fuente et al. (2000) for a survey about the misspecification of econometric studies arising through imprecise measures of human capital.

[7]Yet, those time series studies do not aim a direct estimation of different variants of endogenous growth models.

[8]However, the expected growth rates of the German GDP have been fallen behind in comparison to other E.U.-member countries. For example, the "Frühjahrsgutachten 2001" reports expected growth rates of German GDP around 2.1 to 2.2% for 2001 and 2002 while the mean growth rate

U.S. and German economies. We intend to modify the R&D endogenous growth model which contains scale effects so that this property disappears and then test whether the modified model is compatible with time series evidence. We also will give a qualitative assessment of the new forces of economic growth and the growth performance in the U.S. and Europe.

The paper is organized as follows. In sect. 2 some stylized facts are reported. Sect. 3. presents the R&D model of economic growth. Sect. 4 discusses the time series data and performs the estimation of the model. Sect. 5 gives some qualitative assessment of the new forces of growth for the U.S. and Europe. Sect. 6 concludes the paper.

2 Stylized Time Series Evidence

Already the older literature on economic growth has stressed time series regularities mostly looking at advanced countries since the beginning of the industrialization. The best summary of those stylized facts can be found in Kaldor (1961) who stressed the constancy of the great ratios such as the labor share and capital share in income, the consumption and investment share in income and the income to capital stock ratio among others.[9] One of these facts we would like to point out is a positive per capita growth rate of output over time with no tendency to a decline in the growth rate. This, overall seems to hold for the U.S. as well as European countries.

This is remarkable because the growth theory dominating the economics literature until the 1980's, the Solow (1956), Cass (1965) and Koopmans (1961) models, predicted convergence to a steady state with no growth of per capita income. If positive per capita growth is to be observed in the long run it is the result of exogenous factors, e.g. like exogenous technical progress. Such growth models display positive per capita growth rates only on the transitional path, that is as long as the economy has not yet reached the long run steady state. Arguing that economies are still on the transitional path is not a good explanation either. This holds because on the transitional path the growth rates of output per capita tend to decline over time as the economy approaches its long run steady state. This, however, does not seem to be compatible with time series data. To see this we consider the growth rates of the U.S. and of Germany. In figures 1 and 2 the growth rates of real per capita GDP for these two countries are shown from 1900-1994.[10]

for the E.U. GDP is expected to be around 2.5 to 2.6 %.

[9] We do not repeat all those facts in detail. The reader is referred to Kaldor (1961) or to the introduction in Barro and Sala-i-Martin (1995).

[10] The data are taken from Maddison (1995).

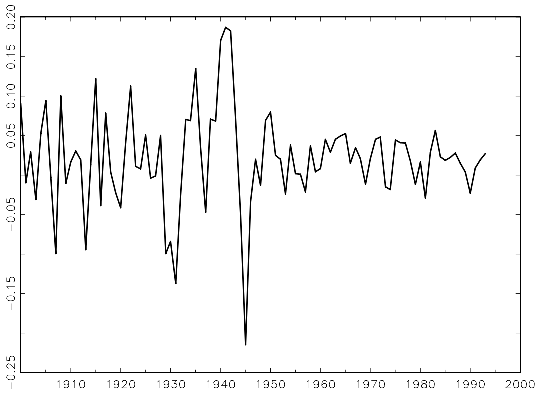

Figure 1: U.S.

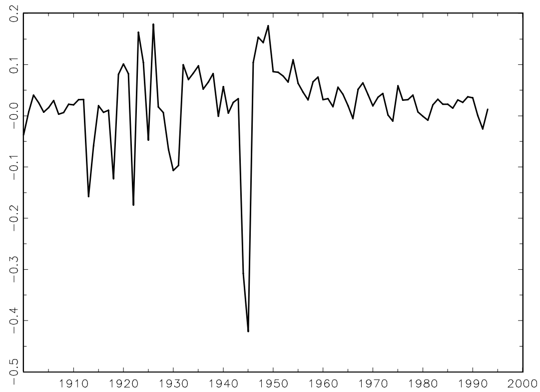

Figure 2: Germany

Table 1: ADF Statistics

	U.S.		Germany	
1900-1994	-5.607	-3.5814^{***}	-5.141	-3.5814^{***}
1950-1982	-3.971	-3.5814^{***}	-2.547	-2.6013^{*}
1950-1994	-5.089	-3.5814^{***}	-3.194	-2.9271^{**}

Critical Values: *: 10 % ; **: 5%; ***: 1%

As figure 1 shows there does not seem to be a tendency of a decline in the growth rates. This is also confirmed by the augmented Dickey-Fuller (ADF) test which clearly rejects the assumption of a unit root.[11] The results of the ADF - statistics are reported in table 1. For the U.S. The ADF test statistic is -5.607 while the 1% percent critical value is -3.503 so that the null hypothesis of a non-stationary time series can be clearly rejected.

Looking at figure 2 one realizes that the same seems to hold for Germany. In this case, the ADF test statistic takes the value -5.141 while the 1% critical value is again given by -3.503. However, if one takes the shorter time period from 1950-1982 this does not seem to hold any longer. In this case, the ADF test statistic is -2.547 while the 10% critical value is -2.615 so that the assumption of non-stationarity cannot be rejected. If one extends the time range and takes the time series from 1950-1994,

[11] The Dickey-Fuller test is a test for the presence of a unit root in a time series which characterizes a non-stationary process.

the augmented ADF test suggests that this series may again be stationary. Now, the ADF test statistic is -3.194 compared to a 5% (1%) critical value of -2.927 (-3.581), implying that the null hypothesis of non-stationarity can be rejected at the 5% percent significance level but not at the 1% significance level. The latter observation seems to suggest that the growth rates of low income countries, compared to the U.S., are higher but decline over time as those countries become richer. This holds for Germany where the physical capital stock had been destroyed to a great degree during World War II and where the level of GDP was low at the beginning of the fifties, compared to the U.S..

These considerations are not a proof for sustained per capita growth but they seem to confirm the stylized facts mentioned above. Indeed, all of the stylized facts observed by Kaldor seem to be confirmed (cf. Barro and Sala-i-Martin, 1995). Yet, exogenous growth theory seems to give an unsatisfactory description of the time series data. Endogenous growth models, however, allow for sustained per capita growth without resorting to exogenous factors and the growth rate becomes endogenously determined. This is the reason why the so-called endogenous growth theory has gained great attention in the economic literature.

As aforementioned in recent empirical work, for example, by Jones (1995a,b, 1997), as mentioned above, attention has shifted to time series implication of the new growth models. In particular, as Jones and others have pointed out, some of the new models predict lasting effects of changes in the level of variables on growth rates. This feature holds, e.g. for the two prototype growth models, namely the Romer (1990) model and the Uzawa-Lucas model as given by the formulation of Lucas (1988).

In the model of Romer (1990) a rise in the amount of resources spent for R&D leads to a higher balanced growth rate implying that the growth rate of GDP positively varies with level of R&D. In reality, however, the amount spent for research and development has risen during the last decades but the growth rate of GDP did not. The same argument holds for the Uzawa-Lucas model. There, a rise in the time spent for education implies a higher growth rate of the stock of human capital which also raises the growth rate of GNP. An increase in the balanced growth rate can also be observed if the ratio of human to physical capital rises. But these features do not seem to hold for advanced economies where the time spent for education as well as the ratio of human to physical capital have risen during the last decades.

The following two tables may illustrate some generic relationships between the level of economic variables and growth rates for the U.S., some European countries and Japan. There, we show some developments from the 1960's to the end of the

1990's. Further trends for the 1990's will be presented in sect. 5.

Table 2: Time trends for Growth Rates, for R&D and for Educational Attainment.

		g_Y	$g_{Y/L}$	$R\&D/GDP$	$\frac{\text{Students}}{\text{Labor Force}}$
US	1961 – 70	0.0406	0.0234	2.7%	7.4%
	1990 – 95	0.0229	0.0119	2.6%	9.1%
	1992 – 98	0.0349	0.0250	2.7%	9.2%
Germany	1961 – 70	0.0436	0.0421	1.8%	1.2%
	1990 – 95	0.0129	0.0110	2.5%	4.8%
	1992 – 98	0.0135	0.0167	2.4%	4.6%
Japan	1961 – 70	0.0966	0.0833	1.7%	–
	1990 – 95	0.0202	0.0099	2.8%	–
	1992 – 98	0.0099	0.0059	–	–
U.K.	1961 – 70	0.0287	0.0280	2.1%	0.7%
	1990 – 95	0.0142	0.0149	1.8%	3.4%
	1992 – 98	0.0251	0.0272	1.7%	3.8%
France	1961 – 70	0.0531	0.0430	1.4%	–
	1990 – 95	0.0126	0.0087	2.4%	5.5% (1980 – 90)
	1992 – 98	0.0148	0.0141	–	7.8% (1990 – 96)

$g_{Y/L}$= annual average GDP growth rate per employed, R&D/GDP= average R&D expenditure as share of GDP, student/Labor Force = measure for educational attainment (sources: see Appendix A).

As Table 2 shows, the U.S. research intensity, measured by $R\&D/GDP$,is highest and remains at a high level compared to the other countries. Yet, overall, the growth rate of output per worker has declined taking five year averages. This holds until the beginning of the 1990's. Only in the 1990's the output per worker again has increased. A similar argument holds for Germany, Japan, the U.K. and France. In those countries, R&D expenditures both in absolute numbers and as share of GDP has increased but the growth rates of output have fallen over the long run and then in the 1990's only increased slightly . The same argument holds with respect to our measure of educational attainment as a proxy for the stock of human capital for countries. Educational attainment has increased over the last thirty years. Yet, it did not seem to have affected the growth rates.

Thus, from the results reported in Table 2, one would be tempted to argue that there do not seem to be growth effects arising from R&D or educational efforts or spending. In most of the countries our variables measuring human capital or R&D effort growth models, increased more than the growth rate but, inspite of this, the long run growth rate of per capita income does not seem to have been affected much. If anything, it has decreased.

The time trends for specific stocks and level variables can be observed in Table 3 where we consider more specifically three countries.

Table 3: Time trends for Growth Rates and Stocks

		$g_{Y/L}$	H/K	H_A/L
U.S.	1961 – 1965	3.58%	17%	0.70 %
	1990 – 1996	1.37%	31%	0.75 %
Germany	1961 – 1965	4.35%	9%	0.22 %
	1991 – 1996	1.35%	21%	0.63 %
UK	1961 – 1965	2.98%	22%	0.25 %
	1990 – 1996	1.59%	26%	0.49 %

$g_{Y/L}$= annual average GDP growth rate per labor force, H/K= ratio of average human capital (cumulative public educational spending) to private capital, H_A= average human capital (number of scientists and engineers) engaged in R&D. See appendix B for the source of $g_{Y/L}$ and for the computation of H/K and H_A/L as the ratio of human capital (in R&D) per labor force.

Table 3 shows the evolution of specific variables which explicitly appear in the two major types of endogenous growth models, the Uzawa-Lucas (1988) human capital and the Romer (1990) R&D model, and contrasts their trends with the average growth rate of GDP. Here again, we see that the stock of human capital has strongly increased, as, for example, compared to physical capital, the growth rates, however, have either remained constant or decreased. This holds for the U.S., Germany and the UK as concerns the ratio H/K (although for the U.K. to a lesser extent). Moreover, it can be seen that in all three countries the number of scientists and engineers engaged in R&D, represented by H_A, has also risen strongly.

Further, comparing the U.S. with Germany one observes that in most relevant variables the U.S. shows higher values compared to Germany, nevertheless the German growth rates of GDP were higher on average particularly in the earlier period.

Altogether, Tables 2 and 3 may indicate that scale effects indeed seem to be missing. This seems to hold generally for all advanced countries. Another way of interpreting the stylized facts is that level variables may have contributed in advanced countries only weakly to output growth. Thus, as we will argue later, increases in level variables, such as the stock of human capital for example, will not proportionally be translated into higher growth rates. There seem to be nonlinearities at work that dampen the growth effects of level variables. In addition, the impact of level variables on growth rates may be weakened by other factors producing lower growth rates. For example, higher tax rates that finance the creation of human capital and R&D may have had offsetting effects which outweigh the contributions of human and knowledge capital to growth. Moreover, there may have been regime shifts in the growth path accompanied with a change in preference or technology parameters.

Besides those endogenous growth models which put strong emphasis on human capital and R&D activities another type of growth models asserts that investment in physical capital is associated with positive externalities which has stimulating effects as concerns the marginal product of physical capital. As a consequence, the marginal product of physical capital does not decline when the capital stock increases but stays constant or even rises. This is the basic endogenous growth model of Romer (1986), where investments in capital are associated with positive externalities. This implies that the marginal product of investment does not decline as the capital stock rises but instead increases. As a consequence, the incentive to invest does not decrease and sustained per capita growth will be generated. However, the assumption that physical capital shows increasing returns does not seem to be justified by empirical observations. For example, the capital stock has risen in the industrialized countries over the last 50 years, but the growth rates have declined. Further, comparing different countries the assumption of increasing returns to physical capital cannot be confirmed in general, for details, see Greiner, Semmler and Gong (2000). Therefore, in the rest of the paper we will not employ the assumption of increasing returns due to externalities. We concentrate, in particular, on a modified version of the Romer (1990)-model. This permits us to shed some light on the most important forces of economic growth, knowledge, human capital and innovations.

3 The R&D Model

Next, we first derive the equations of the R&D model which we will use to get an estimable endogenous growth model.

To do so, we consider the market economy version of the Romer (1990) model (see Benhabib, Perli and Xie, 1994). This economy is composed of three sectors: A research sector which produces new knowledge, an intermediate sector which produces new capital goods and a final goods sector which produces a final good which can either be consumed or invested. The research sector takes human capital and a given stock of knowledge as input factors. This sector behaves competitively. The stock of knowledge, A, is a non-rival good implying that it can be used simultaneously in several economic activities. The motivation for this assumption is that knowledge is independent of any physical object, in contrast to human capital. So it can be copied and used in several activities at the same time without causing major cost.

The intermediate sector uses the knowledge, produced by the research sector, as an input factor and produces intermediate goods, x, which are used as input factors by the final good sector. The firms of the intermediate sector cannot be perfect competitors but must have some market power since they use the non-rival factor knowledge as input. The final good sector employs these intermediate goods together with labor, L, and human capital, H, as input factors and produces the final good.

The production function for final output is given by

$$Y = (H - H_A)^{\alpha} L^{\beta} \int_0^A x(i)^{1-\alpha-\beta} di$$

where $H_Y = H - H_A$ is high qualified labor (human capital) employed in the production of the final good and L is unqualified labor. H is total human capital in the economy and H_A denotes human capital employed in the research sector. $(1 - \alpha) \in (0, 1)$ denotes the capital share. It is assumed that the marginal product of each capital good, $x(i)$, is the same such that each capital good is employed in the same amount. This property is called the symmetry of capital goods. Assuming that symmetry holds the total stock of physical capital can be written as $K = \eta A x$, with η the amount of foregone consumption necessary to produce one unit of the intermediate good. The aggregate production function follows as:

$$Y = \eta^{\alpha+\beta-1} A^{\alpha+\beta} (H - H_A)^{\alpha} L^{\beta} K^{1-\alpha-\beta} \equiv \bar{\eta} A^{\alpha+\beta} (H - H_A)^{\alpha} L^{\beta} K^{1-\alpha-\beta}, \qquad (1)$$

with $\bar{\eta} = \eta^{\alpha+\beta-1}$.

The firms in the final good sector behave competitively. The solution of the optimization problem of the firms producing the final output gives the inverse demand function for the intermediate good $x(i)$, with i standing for firm i, as

$$p(i) = (1 - \alpha - \beta)(H - H_A)^{\alpha} L^{\beta} x(i)^{-\alpha-\beta}. \qquad (2)$$

In order to produce $x(i)$ the intermediate firm first must purchase a design which constitutes a fixed cost investment for it. The intermediate firm takes the function

$p(i)$ as given in solving its optimization problem. The latter is given by

$$\max_{x(i)} \left((1-\alpha-\beta)(H-H_A)^{\alpha} L^{\beta} x(i)^{1-\alpha-\beta} - r\eta x(i)\right), \tag{3}$$

with r denoting the interest rate which is composed of the net interest rate and the depreciation rate. That is we assume that capital is subject to depreciation which raises the costs of the intermediate sector. The cost of the intermediate sector is the cost on the ηx units of final output which are needed to produce x durables. The solution to this problem yields the interest rate as

$$r = \bar{\eta}\,(1-\alpha-\beta)^2 (H-H_A)^{\alpha} A^{\alpha+\beta} L^{\beta} K^{-\alpha-\beta}. \tag{4}$$

It should be noted that $p(i) = (\eta/(1-\alpha-\beta))r$ holds demonstrating that the price the firm of the intermediate sector sets is just a markup over the marginal cost r. Thus, the profit of the intermediate firm can be written as

$$\pi = p(i)x - r\eta x = \eta(\alpha+\beta)rx/(1-\alpha-\beta). \tag{5}$$

Since knowledge is a non-rival good each firm has access to the entire stock in the economy. The production of new knowledge of firm i is supposed to be given by $g_A(i) = \mu H_A(i)^{\gamma} A^{\phi} - \delta_A A$, with $H_A(i)$ the amount of human capital used in the production process by firm i and $\delta_A \in (0,1)$ the depreciation rate of knowledge. This function differs from the one used in the original model by Romer (1990).[12] The motivation for this change will be discussed below. The differential equation describing the evolution of the stock of knowledge A is obtained by aggregation across firms giving

$$\frac{\dot{A}}{A} = \mu H_A^{\gamma} A^{\phi-1} - \delta_A, \tag{6}$$

with $\gamma, \phi \in (0,1)$.

The price of knowledge at time t, $P_A(t)$, is equal to the present value of the stream of profits of each intermediate firm. This holds because the research sector behaves competitively. This leads to a differential equation describing $P_A(t)$ over time, which is

$$\dot{P}_A = rP_A - \pi. \tag{7}$$

In the equilibrium the rental rate of human capital in the final good sector and in the research sector must be equal. If both sectors behave competitively this implies

$$P_A = \bar{\eta}\alpha A^{\alpha+\beta-\phi}(H-H_A)^{\alpha-1} L^{\beta} K^{1-\alpha-\beta} H_A^{1-\gamma}/(\mu\gamma). \tag{8}$$

[12] This function was introduced by Jones (1995b). The difference to his model is that we explicitly distinguish between skilled labor, H, and unskilled labor, L.

Taking logarithms and differentiating with respect to time yields an expression for $\dot{P}_A/P_A$, which is given by

$$\frac{\dot{P}_A}{P_A} = (1-\alpha-\beta)\frac{\dot{K}}{K} + (\alpha+\beta-\phi)\frac{\dot{A}}{A} + (\alpha-1)\frac{\dot{H}-\dot{H}_A}{H-H_A} + (1-\gamma)\frac{\dot{H}_A}{H_A} + \beta\,\frac{\dot{L}}{L}. \quad (9)$$

On the other hand, combining (7) and (8) and using the expression for π as well as $x = K/(\eta A)$ yields

$$\frac{\dot{P}_A}{P_A} = r - \frac{\mu\gamma(1-\alpha-\beta)\,(H-H_A)\,A^{\phi-1}H_A^{\gamma-1}}{\alpha}. \quad (10)$$

Setting (9) and (10) equal and solving for $\dot{H}_A$ leads to

$$\begin{aligned}\dot{H}_A \;=\; & ((1-\alpha)H_A + (1-\gamma)(H-H_A))^{-1}\Big(H_A(H-H_A)\Big(\frac{C}{K}(1-\alpha-\beta) + \\ & \delta_K(1-\alpha-\beta) - (\mu H_A^{\gamma}A^{\phi-1} - \delta_A)(\alpha+\beta-\phi) - \beta\, n - \\ & \bar{\eta}K^{-\alpha-\beta}A^{\alpha+\beta}(H-H_A)^{\alpha}L^{\beta}(1-\alpha-\beta)(\alpha+\beta)\Big) + (1-\alpha)n_H H H_A - \\ & \frac{\alpha+\beta}{\alpha}(1-\alpha-\beta)\mu\gamma A^{\phi-1}(H-H_A)^2 H_A^{\gamma}\Big), \qquad (11)\end{aligned}$$

with $\delta_K \in (0,1)$ the depreciation rate of physical capital. The capital accumulation equation is

$$\dot{K} = Y - C - \delta_K K = \bar{\eta}A^{\alpha+\beta}(H-H_A)^{\alpha}L^{\beta}K^{1-\alpha-\beta} - C - \delta_K K, \quad (12)$$

where C denotes aggregate consumption.

The parameters n_H and n denote the growth rate of the total stock of human capital H and the growth rate of labor supply L respectively, i.e.

$$\dot{H} = Hn_H \quad (13)$$

$$\dot{L} = Ln. \quad (14)$$

Table 4 gives a survey of the productive sector in the Romer model.

Table 4: Survey of the productive sectors in the Romer model.

R&D Sector	Intermediate Goods Sector	Final Goods Sector
$\dot{A} = \mu H_A^{\gamma}A^{\phi} - \delta_A A$	produces $x(i)$ using Y, buys a design (fixed cost)	$Y = (H-H_A)^{\alpha}L^{\beta}\int_0^A x(i)^{1-\alpha-\beta}di$
competitive	monopolistic	competitive

The model is completed by describing the household sector. The latter is represented by representative household that maximizes the discounted stream of utilities over an infinite time horizon subject to a budget constraint. Formally, the utility functional of the household is written as

$$\int_0^\infty \frac{C^{1-\sigma}-1}{1-\sigma} e^{-\rho t} dt, \tag{15}$$

where ρ denotes the subjective discount rate and σ the inverse of the intertemporal elasticity of substitution of consumption between two points in time. The budget constraint of the household is given by

$$\dot{K} = rK + w_L L + w_H H - C, \tag{16}$$

with w_L and w_H the wage rate for labor and for human capital respectively. Maximizing (15) subject to the budget constraint (16) gives the growth rate of aggregate consumption as

$$\frac{\dot{C}}{C} = \frac{r(t)-\rho}{\sigma} = \frac{\bar{\eta}}{\sigma}(1-\alpha-\beta)^2 (H-H_A)^{\alpha+\beta} A^{\alpha} L^{\beta} K^{-\alpha-\beta} - \frac{\rho+\delta_K}{\sigma}. \tag{17}$$

Our system, containing only observable variables, is given by equations (6), (11), (12), (13), (14) and (17). It should be noted that the major innovation in the above model in contrast to the original Romer (1990) model is the production function of knowledge (equ. 6). The presence of $\phi \in (0,1)$ in equation (6) intends to capture the fact that the higher the stock of knowledge, the more difficult it becomes to create new knowledge. That is it captures the effect of satiation. The presence of $\gamma \in (0,1)$ captures some congestion effects of new researchers or research institutions leading to decreasing returns. If, ceteris paribus, the number of researchers or research institutes double, the number of new designs, may not double. Some research institutes may duplicate the results of others and their marginal contribution may be less than the average contribution to the creation of knowledge. If we measure it in terms of patents per scientist and engineer the time series data in sect. 5 show that there is indeed a downward trend.

Such a modification is necessary in order to make the Romer (1990) model compatible with time series evidence since the original model contains scale effects. In order to estimate the model, in particular the production function of knowledge, of Romer (1990) has to be altered.[13]

Before we estimate our model, we will define a BGP for our generalized Romer model. A BGP is defined as a path where the output to capital ratio, Y/K, is constant and all variables grow at constant but possibly different rates. The assumption

[13] As to the construction of the data, see the next section.

of a constant output to capital ratio implies a constant consumption to capital ratio. Thus, we can state that on a BGP we have:

$$\frac{\dot{Y}}{Y} = \frac{\dot{K}}{K} = \frac{\dot{C}}{C}\,.$$

Further, constant growth rates imply $d/dt\,(\dot{A}/A) = 0$ and $d/dt\,(\dot{K}/K) = 0$. Differentiating (6) and (12) with respect to time and setting the left hand side equal to zero yields

$$\frac{\dot{A}}{A} = \frac{\gamma}{1-\phi}\frac{\dot{H}_A}{H_A}$$

and

$$\frac{\dot{K}}{K} = n + \frac{\gamma}{1-\phi}\frac{\dot{H}_A}{H_A} + \frac{\dot{H}_Y}{H_Y}\,.$$

Moreover, setting (9) equal to (10) demonstrates that H_A and H_Y grow at the same rate on a BGP. Further, the growth rate of H_A and H_Y must be equal to the growth rate of H, n_H. Thus, the BGP for the modified Romer model is given by

$$\frac{\dot{Y}}{Y} - n - n_H = \frac{\dot{K}}{K} - n - n_H = \frac{\dot{C}}{C} - n - n_H = \left(\frac{\gamma}{1-\phi}\right) n_H\,. \tag{18}$$

This result shows that, in the modified Romer model, the long run growth rates of aggregate variables are larger than the growth rates of labor and human capital. Thus, the modified Romer model generates positive per capita growth[14] in the long run. However, the balanced growth rate is determined by the parameters of the knowledge production function, γ and ϕ, and by the growth rate of labor, n, and of human capital, n_H. It can also be seen that the growth rate of aggregate variables just equals the growth rate of labor in the long run if the growth rate of human capital equals zero. This follows immediately from (18).

This outcome has far-reaching consequences for economic policies in specific countries. While in the original Romer model the balanced growth rate can be affected by conventional government policies, such as a subsidy leading to more human capital in the research sector, this does not hold any longer for our modified model. There, the government may raise the balanced growth only if it succeeds to raise the growth rate of human capital or if it has influence on the parameters in the production function of knowledge. Because of this property, such a modified Romer model belongs to the so-called semi-endogenous growth models. This means that positive per capita growth can be observed in the long run, but the government

[14]This holds because the per capita growth rate of output is given by $\dot{Y}/Y - n(L/(L+H)) - n_H(H/(L+H)) > \dot{Y}/Y - n - n_H$.

can affect the long run balanced growth rate only by increasing the growth rate of human capital or influencing the parameters in the production of knowledge .

The modification of the production function of knowledge capital as shown in equation (6) is necessary in order to eliminate (unrealistic) scale effects present in the original Romer model. However, using equation (6) is not the only possibility to eliminate scale effects, other modifications are feasible as well. In the case of the Romer model it may be advisable to assume an exogenous time trend. The major modification of the original function then is to assume that μ explicitly depends on time. The function then can be written as

$$\frac{\dot{A}}{A} = \mu(t)\, H_A^{\gamma} - \delta_A. \tag{19}$$

From an economic point of view this can be justified by economic variables which affect the growth rate of knowledge but which are not explicitly considered in the production function of knowledge, like physical capital or public subsidies.

With this equation the Romer model may again yield positive per capita growth even if the growth rate of human capital equals zero. This can be seen as follows. Assume that the growth rates of labor and human capital are zero and $\mu(t)$ is constant. Then, on a BGP the growth rate of human capital in R&D equals zero, too. This implies that the right hand side in (19) is constant. If it is positive knowledge grows without a bound and may lead to sustained per capita growth in the long run. However, the emergence of positive per capita growth depends on the values of the parameters in the model and a situation with no sustained per capita growth is feasible as well.

4 Estimation Results

The modified Romer model is completely described by the equations (6), (11), (12), (13), (14) and (17) written in respective growth rates. In estimating this model for specific countries it turns out that we have to make some compromises in order to get reasonable results. First, trying to estimate the model including equation (11) did produce only unrealistic results. Thereby, the problem occured that it was not possible to find parameters γ and ϕ which matched the time series (6) and (11) simultaneously. Therefore, we assume H_A as an exogenous variable. Second, a similar problem was encountered when we tried to estimate (17). There, the growth rate of C turned out to be constant implying that the right hand side must be a constant, too. Therefore, we had to change the aggregate production function and we took $Y = \bar{\eta}(A(H - H_A)L)^{\alpha} K^{1-\alpha}$. This reduces the set of parameters to be estimated to one. We thus estimate a system of equations which is motivated by the Romer model but not identical to it. With these modifications, the system we estimate is given by equations

$$\frac{\dot{K}}{K} = \bar{\eta}K^{-\alpha}(A(H-H_A)L)^{\alpha} - \frac{C}{K} - \delta_K \tag{20}$$

$$\frac{\dot{C}}{C} = \frac{\bar{\eta}}{\sigma}(1-\alpha)^2(A(H-H_A)L)^{\alpha}K^{-\alpha} - \frac{\rho+\delta_K}{\sigma} \tag{21}$$

$$\frac{\dot{A}}{A} = \mu H_A^{\gamma}A^{\phi-1} - \delta_A, \tag{22}$$

while the growth rate of H_A is taken from empirical observations. We apply the Generalized Methods of Moments (GMM) Estimation to equs. (20) -(22).[15] The empirical estimation is undertaken for the following parameter set

$$\psi = ((1-\alpha), \bar{\eta}, \rho, \sigma, \mu, \gamma, \phi, \delta_A).$$

The growth rates n and n_H are predetermined parameters obtained from empirical observations and δ_K is also a predetermined parameter which takes the value used in constructing the time series of physical capital ($\delta_K = 0.025$).

The achieved results for the U.S. and Germany are shown in table 5. Standard errors are given in parenthesis.

Table 5: Estimation of the modified Romer Model

	U.S.		**Germany**	
Parameter	value	(std. err.)	value	(std. err.)
$(1-\alpha)$	0.39	(0.0031)	0.36	(0.0052)
$\bar{\eta}$	0.0008	(6.9e-005)	0.0007	(0.0001)
ρ	0.0075	(0.0058)	0.0077	(0.0027)
σ	2.055	(0.6906)	0.8396	(0.32)
μ	1.0081	(0.006)	1.0006	(0.0042)
γ	0.0004	(0.0014)	0.0001	(0.0011)
ϕ	0.099	(0.0012)	0.083	(0.0009)
δ_A	0.006	(6.0e-005)	0.007	(6.4e-005)

Comparing the two countries we can say that most of the parameters fall in a reasonable range. In particular, the capital share, $(1-\alpha)$, which is slightly smaller

[15] As to the data construction and the estimation strategies, see Greiner, Semmler and Gong (2000) and for the data sources, see appendix B.

than 40 percent takes reasonable values in both countries. The same holds for the preference parameters. The (annual) subjective discount rate is about 3 percent[16] and the value of the intertemporal elasticity of substitution of consumption, $1/\sigma$, also falls in every estimation in a reasonable interval between 0.5 and 1.2. Further, all structural parameters turn out to be statistically significant, with the exception of ρ for the U.S. which has a relatively high standard deviation.

As to the parameters of the knowledge production function (6) we see that the parameter for the elasticity of knowledge production with respect to human capital, γ, is not statistically significant in both countries. So, the interpretation of this coefficient must be taken with care. As to the absolute value, it is very low in both countries. This reflects the fact that the growth rate of knowledge capital, $\dot{A}/A$, declines while the the stock of human capital employed in R&D rises, see again Figure 9 in sect. 5. The parameter ϕ which captures the degree of satiation, however, is significant both for the U.S. and Germany. The low value for ϕ of about 8-10 percent implies a high degree of satiation. This is a consequence of the fact that the time series of the growth rate of knowledge capital and the time series of the stock of knowledge show two different trends. While the growth rate of knowledge capital strongly declines the stock of knowledge as a level variable rises.

The capital share in the model is between 36 and 39 percent. The (annual) subjective rate of time preference lies between about 3 and 10 percent. As to the intertemporal elasticity of substitution of consumption between two points in time, $1/\sigma$, our estimations show that this coefficient is higher for the U.S. than for Germany. This outcome implies a tendency to a higher growth rate of aggregate consumption in Germany than in the U.S. which is compatible with the time series for the time period we consider.

An important role in the Romer model and in estimating our system plays equation (6). Besides our assumption of satiation, and decreasing returns to human capital in this sector, captured by the parameters ϕ, and γ, the growth rate of knowledge may also depend on an exogenous time trend. For example, this can be taken into account by postulating that the coefficient μ is a function depending on time as mentioned above. For our model we use equ. (19) which we introduced above. This equation is given by

$$\frac{\dot{A}}{A} = \mu(t)\, H_A^{\gamma} - \delta_A.$$

[16]Note, that we employ quarterly data in our estimations. Therefore, the estimated values of ρ have to be multiplied by 4 in order to obtain their annual values.

As to $\mu(t)$ we assume a function such as

$$\mu(t) = \frac{\mu_0}{\theta(t)} \tag{23}$$

where $\theta(t)$ follows the dynamics

$$\theta(t) = \beta\theta(t-1) + \nu \tag{24}$$

with the initial condition $\theta(0) = 1$. Note that β denotes the regression coefficient and ν the disturbance term.

Estimating the Romer model with (19) instead of equation (22) shows that the parameters in equations (20) and (21) do not change. This is due to the fact that the parameters in the production function for knowledge appear only in this equation and not in the other two. The estimation results for the parameters of equation (19) are shown in table 6.

Table 6: Estimation of Romer model with equation (19)

	U.S.		**Germany**	
Parameter	value	(std. err.)	value	(std. err.)
δ_K	0.0025	(1.08 e-005)	0.0363	(8.2 e-005)
γ	0.476	(0.001)	0.1	(0.0006)
δ_A	0.0076	(4.9 e-005)	0.0329	(9.4 e-005)
ν	0.041	(0.0002)	0.033	(0.0001)
β	0.982	(0.0522)	0.978	(0.0286)

Table 6 shows that all of the estimated coefficients are now statistically significant. This also holds for the elasticity of growth rate of knowledge with respect to human capital in this sector which is about 48 percent for the U.S. and 10 percent for Germany. The function $\mu(t)$ depends on time negatively. This implies that there is a negative time trend tending to reduce the growth rate of knowledge. This allows the interpretation that the significant (negative) correlation of the time trend, with $\dot{A}/A$ indicates, other forces to be relevant for the accumulation of knowledge. Moreover, comparing the U.S. and Germany, we see from the time series data of Figure 9 that this decline has happened faster for Germany than for the U.S..

5 Qualitative Assessment of the New Forces of Economic Growth

Although, the long-run growth rate of the modified model appear to be determined also by exogenous forces, we want to shed some light on the endogenous forces of growth. The original models of Romer (1990) and Lucas (1988) stresses inventive activities and the creation of knowledge and human capital as the determinants of long run economic growth; in contrast to the 'old' Solow growth theory. Secondly, the Schumpeterian prediction of growth points out that, for example, an increase in the R & D spending is positively correlated with the long run growth rate[17]. Especially one goal of our work was to confront an endogenous growth model with time series data for specific countries, in our case for the U.S. and Germany. In particular, we want to know how the 'growth – factors', knowledge human capital and innovation differ across countries.

Furthermore, in line with recent OECD studies[18], we present a collection of time series evidences for three important OECD - member countries, the U.S., the U.K. and Germany. We will see that, particular since the 1980's, the U.S. dominates the comparison of the new growth - forces.

According to our model (see sect. 3) and Aghion and Howitt (1998a)[19] we define knowledge capital as the outcome of innovative activities. In this section we take R&D - investments and the number Scientists and Engineers as the main inputs and the number of national patent grants as outputs.[20] Figures 3 and 4 show R&D - expenditure as a fraction of GDP[21] and industry R&D as a fraction of total R&D.

[17]See e.g. Aghion and Howitt (1998a: 484).

[18]See e.g. Bassanini et al. (2000), OECD (2000) or Schreyer (2000).

[19]See Aghion and Howitt (1998a), ch. 12.

[20]Of course, there is a huge number of variables determining innovative activities but a lot of them are not available as time series data. Our measurement provides some selected long-run time series evidence for each country.

[21]Note that R&D - expenditure means total expenditure including defense expenditure.

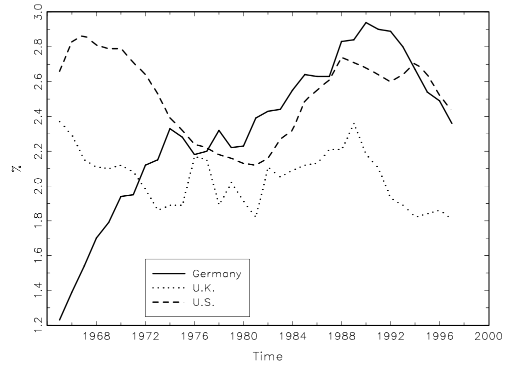

Figure 3: Total R&D - Expenditures in % of GDP 1965 – 1997

Sources: National Statistics and own calculations

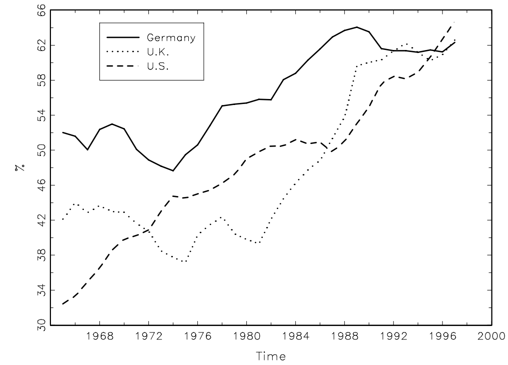

Figure 4: Industrial R&D in % of Total R&D 1965 – 1997

Sources: National Statistics and own calculations

Figures 3 and 4 show how R&D - expenditures behave across three main OECD - countries[22]. We observe high R&D to GDP - ratios for the U.S. and Germany while for the U.K. this fraction remains at a lower level. We observe also that each ratio increases until the middle of the 1980's and shows decreasing patterns since the beginning of the 1990's.

On the other hand, figure 4 shows the increase of the ratio of industrial R&D - expenditure relative to total R&D. This expenditure accounts for about 50% (and more) of total R&D - investment. One might interpret this result as evidence of the allocation of inventive investment as indicated in the growth model studied in sect. 3. In particular, we observe that this ratio increases strongly since the middle of the 1980's for the U.S. whereas it remains nearly constant for the European Countries. One might take this as evidence for the beginning IT-revolution in the U.S..

Another input for creating new knowledge are scientists and engineers (S&E) engaged in the R&D - sector. Figure 5 below shows the number of S&E in per cent of total labor force.

[22] See Appendix A for the sources of the data presented in this section.

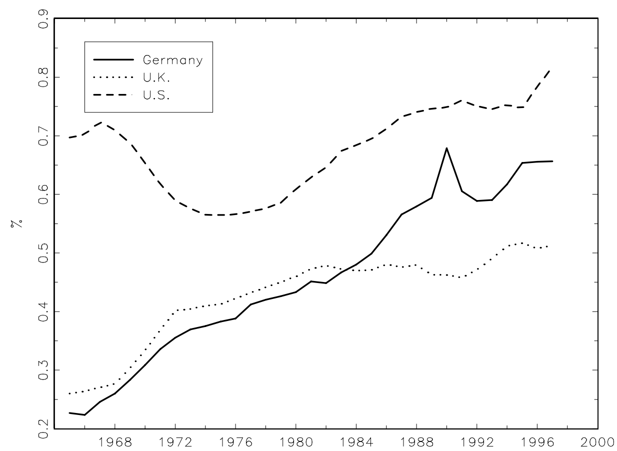

Figure 5: Scientists & Engineers per Labor Force (1965-97)
Sources: OECD (1998) and own calculations

Figure 5 shows some differences across the countries. For the U.S. the number of S&E remains at a high and constant level and shows a sharp increase first since the beginning of the 1980's and then in the 1990's. The German time series is increasing steadily until the reunification in 1990 and then falls off. In recent years the number of S&E remains nearly constant. The U.K. series increases since the middle of the 1980's and stays at a constant level at around 0.45 % and thus is lower compared to the other countries.

Although the total number of scientists and engineers increased during the last decades we observe that the employment structure behaves differently. Table 7 shows the number of scientists employed in the business sector in per cent of total scientists.

Table 7: Scientists employed in the Business Sector in % of Total S & E.

Country	**1989**	**1991**	**1993**	**1995**
Germany	64.2	58.3	56.0	56.0
France	45.1	45.9	45.5	44.0
Japan	56.0	57.0	57.3	57.0
U.K.	63.9	62.5	63.7	56.8
U.S.	79.3	80.8	79.4	n.a.

Source: OECD (1998), BMBF (2000)

As Table 6 shows the U.S. has a high percentage of scientists engaged in the business sector. Any other country shows significantly lower levels than the U.S.. For Germany we observe that the relative number of scientists engaged in the business sector is lower than in the U.S. and decreases by 8 % from 1989 to 1995. Comparing the R&D - inputs across the countries we so far already can conclude that the U.S. economy is the worldwide leader in the effort to produce new innovations and technologies.

According to the literature[23] another important factor are so-called General Purpose technologies (GPT). If GPT is available for every worker, in particular high educated ones, it has an important influence on the productivity of each sector. Such technology provides the access to research results, inventions and innovations and allow for productivity increases. An accepted measure of GPT are investments in information and communication technologies.

Table 8: ICT – Investments in % of Total Investments

	Germany *(Western Germany)*	France	U.K.	U.S.	Japan
IT – Invest.					
1985	3.4	6.1	5.2	6.3	3.4
1990	3.5	5.0	7.5	8.7	3.8
1996	6.1	6.0	11.7	13.4	4.6
Comm. – Invest.					
1985	3.7	4.0	5.2	5.8	0.8
1990	3.7	3.8	5.8	7.0	1.5
1996	4.8	4.9	6.6	6.5	3.5

Source: Schreyer (2000)

Table 8 shows that the U.S. and the U.K. show the highest increase (and level) of ICT - investment compared to the other countries. For Germany ICT investment doubled too, but it's level is about one half of the one of the U.K. or the U.S..

Defining human capital as cumulative educational expenditure we will present two approximations of such activities. The following figures present indicators for the stock of human capital. Figure 6 shows the ratio of educational expenditures to GDP. Figure 7 presents the ratio of students to the labor force.

[23]See e.g. Schreyer (2000) or Aghion and Howitt (1998b).

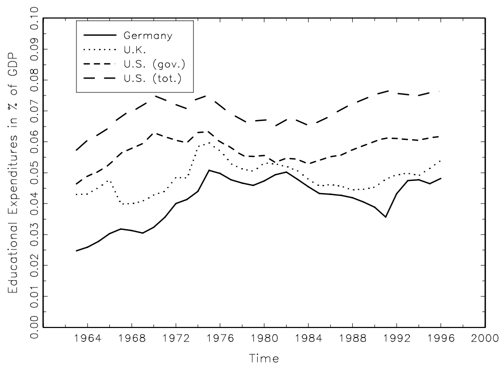

Figure 6: Educational Expenditures per GDP

Sources: National Statistics and own calculations

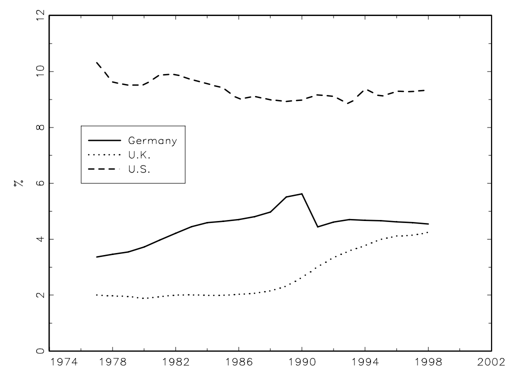

Figure 7: Students per labor force

Sources: National Statistics and own calculations

Similar to other results we observe a dominating position of the U.S.. The U.S. devotes the highest amount of investments to the educational system compared to European countries. The same can be observed if we compare the number of students at colleges and universities (in per cent per labor force) for the U.S. and Europe.

As argued in sect. 3 the increase in the level of human capital, R&D and Scientist and engineers may not necessarily increase the growth rate of an economy. Figure 8 concentrates on the output of human capital build up and innovative activities. It presents the number of national patent grants of the U.S., the U.K. and Germany. Figure 9 shows the number of patents per scientist and engineer.

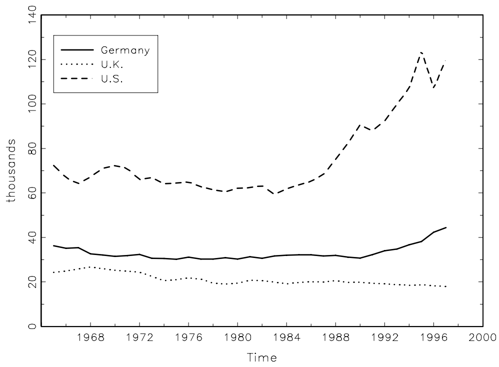

Figure 8: National Patent Grants

Source: National Statistics

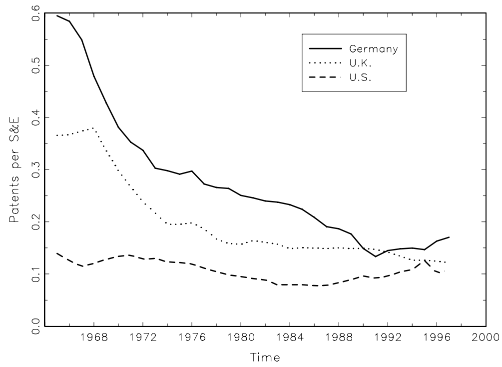

Figure 9: National Patent Grants per S&E.

Source: Own computations

Concentrating on the number of patents, see Figure 8, the U.S. and Germany show an increasing trend with the U.S. above Germany while the U.K. shows a decreasing trend. Although the U.K. shows a positive pattern of innovative inputs (see figures 3 to 5 and table 8) the number of outputs decreased. This holds even more so for Germany. The result of Figure 9 again indicates the same problem as discussed in sections 3-4 namely, that further innovative efforts may not lead to a higher productivity. Although the U.S. has been the dominant country in most of the new forces of economic growth, we also could show that there are limits to increase economic growth rates. Yet, as Table 1 in sect. 2 shows the U.S. could considerable increase its output per worker in the 1990's.

6 Conclusion

In this paper we discussed the new forces of economic growth as they are predicted by the new growth theory. We have presented stylized facts on those forces for the U.S. and E.U. countries. Further, we formulated and estimated a transformed R&D model of endogenous growth with time series data for the U.S. and German economies. We obtained reasonable parameter estimates. Our results are consistent with the interpretation of the stylized fact that there are no scale effects present in real time series data and that, in fact, the output effects of innovative efforts, for the U.S. as well as European countries have declined.

We saw that the Romer model is compatible with those time series trends only if scale effects, present in the original model, are eliminated from that model. However, if one does not resort to an exogenous function in order to eliminate these scale effects this has important consequences from a theoretical point of view. So, in the modified Romer model the growth rate of aggregate variables exceeds the growth rate of labor input only if growth rate of human capital in the research sector is positive. That is in order to achieve an aggregate growth which is larger than the growth rate of labor the stock of human capital devoted to the production of knowledge must rise over time. This also has implications for economic policy. Since the growth rate of human capital devoted to knowledge production cannot exceed the population growth the implication for economic policy is that the government can affect only the transitory growth rate by some policies but not the long run per capita growth rate for ever.

If scale effects are replaced by exogenous factors, represented by our estimated time trend, this time trend is crucial as to the result of the Romer model. If this exogenous impact, i.e. the time trend, converges to a constant the Romer model may still yield positive per capita growth in the long run, even if human capital in the R&D sector is constant. This depends on the parameters of the model.

Furthermore, our comparisons of the efforts of the human capital building and R&D investments have shown that although the output per unit of those activities measured as patents, appear to decline for advanced countries the U.S. has a dominant position concerning those efforts. Those efforts seem to have substantially contributed to the high growth rate of GDP for a considerable period of time and to the high rate of job creation in the U.S. in the 1990's, in contrast to the widely held view that this was caused by flexible labor market in the U.S.. The flip-side is that Europe – in our study represented by its largest economy, Germany – may have fallen behind in growth and in job creation less because of labor market rigidities but more because it was lagging in the creation of human capital, R&D effort and creation of knowledge based industries. Although, as above shown, there are limits to what extent the new forces of economic growth can affect long run growth rates there seem to be transitional effects that appear to have significantly affected the U.S. growth rates.

Appendix

A Data Sources of Sections 2 and 5

All data are measured in constant prices with 1990 = 100. Sources and computations of stocks H, K and H_A are discussed in Appendix B. Data sources of Tables 2 and 3 and of sect. 5 are:

- $g_{Y/L}$, own computations with data taken from OECD (2000).
- *R&D:* for the U.S., see National Science Foundation (2000), Office for National Statistics (1965)-(1998), for Germany, see Bundesministerium für Bildung und Forschung (BMBF)(2000), for the other countries see OECD (1980-1998).
- *Educational Attainment:* For the U.S., National Science Foundation (2000) and Office for National Statistics (U.K.) (1965)-(1998), for Germany, see Statistisches Bundesamt (1977), (1991)-(1996).
- *Scientists and Engineers engaged in R&D:* See OECD (1980)-(1998), for Germany, see Institut der deutschen Wirtschaft (2000), for the U.S., see National Science Foundation (1998), (2000).
- *Scientists and Engineers employed in the Business Sector*, see OECD (1998), Bundesministerium für Bildung und Forschung,(2000).

B Data Construction and Data Sources of Sections 2 and 4

Note that data construction and preliminary estimation for the sect. 4 are given in Greiner, Semmler and Gong (2000). Here we briefly want to report the sources of our data. The time series data are quarterly data for both the U.S. and Germany. For the U.S. we use data from 1962.1-1990.4, for Germany the data are from 1962.1-1991.4.[24] The data for consumption, physical capital investment and labor are taken from OECD, Business Sector Database (1999.1). Physical capital was constructed using the perpetual inventory method (see Park, 1995). These data were available quarterly.

As to the stock of human capital H we construct this variable from educational spending using the perpetual inventory method. As to the stock of skilled labor,

[24] Data for Germany are for West Germany only.

employed in research, H_A, and the knowledge capital, or the stock of designs, A, as Romer (1990) calls it, we also compute those stocks from expenditure flows by using the perpetual inventory method. As a proxy for the stock of skilled labor, H_A, employed in the production of knowledge capital (designs), we take cumulated salaries for scientists and engineers, whereby the stock H_A is computed in the same way as H. Furthermore, the stock of knowledge is computed from total expenditure for R&D.

The data for salaries in the R&D sector and total expenditures for R&D are from National Science Foundation (2000) and Office for National Statistics (1965)-(1998) for the U.S. and belong to own calculations with data taken from the Statistisches Bundesamt (1991)-(1999) for Germany. The number of researchers was obtained from OECD (1998) for both the U.S. and Germany. For this time series quarterly data were computed from annual data using linear interpolation. Further, all data are real data.

We want to note that Jones (1997) uses different measures for H_Y and H_A where H_Y is measured by hL_Y and hL_A, respectively. Hereby he assumes that the human capital, h, is exponentially growing, L_Y being the labor force in final production and L_A the labor force employed in knowledge production. However, because we have used cumulative educational expenditure as a proxy for human capital, H, the fraction of human capital used in the R&D sector, H_A, should also be constructed using a monetary proxy. Further, using total salaries in the R&D sector as proxy has the advantage that the labor input receives a certain weight which is equal to the wages paid to the employees in this sector. Since the wage reflects the productivity of labor an increase in the wage implies that labor input becomes more productive which has a positive effect on output. This is captured by taking the wage rate as a weight on labor input. Because of those reasons, we decided to take total cumulative salaries in R&D as a proxy for human capital employed in this sector.

C International and National Data Sources

This section provides the sources of the data sets used in this work.

International data sources:

- OECD, Paris, Statistical Compendium, CD-ROM Release 1999.1 and 2000.1
  - Business Sector Database (BSDB)
  - National Accounts I + II
- OECD, Paris, *Main Science and Technological Indicators*, Rel. 1988-1998.

- OECD, Paris, *Education at a glance*, 1992, 1996, 2000
- OECD, Paris, *Employment Outlook*, 1994
- UNESCO, Paris, *World Education Indicators* 1998, 2000,
  Internet source: `http://unescostat.unesco.org/`

National data sources, Germany:

- Statistisches Bundesamt, Wiesbaden:
  - Sachverständigenrat (1999), "Vor weitreichenden Entscheidungen - Jahresgutachten 1998/99", Metzler-Poeschel, Stuttgart.
  - Fachserie 4, "Bildung und Kultur", Reihe 4.4, 1970, 1980, 1987 und 1995.
  - Statistisches Jahrbuch der Bundesrepublik Deutschland, Metzler-Poeschel, Wiesbaden 1990-1998.
- Bundesbericht Forschung 1996, Bundesministerium für Bildung, Wissenschaft und Forschung und Technologie (Hrsg.), CD-ROM-Version August 1996.
- Bundesministerium für Bildung und Forschung (BMBF) 2000, *Grund- und Strukturdaten 1999/2000*, Bonn.
- Deutsches Patentamt, Referat Statistik, "Patentanmeldungen in der BRD", 1999, München.

National data sources, U.S.:

- National Science Foundation (NSF):
  - Science & Engineering Indicators 1996, 1998, 2000,
    Internet source `http://www.nsf.gov/`
  - National Patterns of R&D - Resources 1998,
    Internet source `http://www.nsf.gov/`
- U.S. Department of Education, National Center for Education Statistics, *Digest of Educational Statistics, 1997*,
  Internet source `http://nces.ed.gov/pubs/digest1997/d97+099.html`
- U.S. Bureau of the Census, *Annual Statistical Abstract of the U.S. 1970 - 1999".*

National data sources, U.K.:

- Office for National Statistics, *Annual Abstract of Statistics*, 1965 - 1998.

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