



Center for Empirical Macroeconomics

Working Paper No. 16

**Economic Growth, Skill-Biased Technical Change
and Wage Inequality: A Model and Estimations
for the U.S. and Europe**

by

Alfred Greiner, Jens Rubart and Willi Semmler

University of Bielefeld
Department of Economics
Center for Empirical Macroeconomics
P.O. Box 100 131
33501 Bielefeld, Germany

Economic Growth, Skill-Biased Technical Change and Wage Inequality: A Model and Estimations for the U.S. and Europe*

Alfred Greiner**, Jens Rubart[‡] and Willi Semmler[†]

February 2003

Abstract

In recent literature skill-biased technical change has been viewed as a major cause for wage inequality. Some modelling and presentation of stylized facts have been undertaken for U.S. time series data. A preliminary study of wage inequality in a model with knowledge as input in an aggregate production function has been presented by Murphy, Riddell and Romer (1998). Although some important forces determining wage inequality are widely accepted we know little about the quantitative impact of each source and differences across countries. We present a growth model of the Romer type with innovation based technical change and two skill groups where the growth of knowledge, the relative supply of the two skill groups, externalities and substitution effects among the two groups are the driving forces for wage inequality. We undertake estimates for U.S. time series data and contrast those estimates with results from some European countries. In particular, we compare parameter estimations for U.S. and German time series data. The paper concludes that there is less wage inequality across skills in Europe in contrast to the U.S. on the macroeconomic level. But, considering disaggregated data we observe some increase in inequality for Germany, too. Although our model reveals important variables for the explanation of wage inequality there may, however, also be other factors, such as trade unions, which have impacted the wage spread.

Key Words: Economic growth, skill-biased technological change, wage inequality

JEL - Classification: J0, O3.

*We want to thank Phillipe Aghion for extensive discussions. Willi Semmler wants to acknowledge financial support from the CEPA of the New School University and from the Ministry of Science and Technology of the State Northrhine-Westfalia, Germany. We are also grateful for comments by a referee of the journal.

**Dept. of Economics, Bielefeld University, Germany, e-mail: agreiner@wiwi.uni-bielefeld.de

[‡]Institute of Economics, Darmstadt University of Technology, Germany and Center for Empirical Macroeconomics, e-mail: rubart@vwl.tu-darmstadt.de.

[†]Center for Empirical Macroeconomics, Bielefeld University, Germany, and New School University, New York, e-mail: wsemmler@wiwi.uni-bielefeld.de.

1 Introduction

Comparing the labor markets of various OECD-member countries we can, for some countries, observe an increasing wage inequality over time. Although numerous studies on wage inequality exist the sources of such inequality are not completely understood.

In order to shed some light on the driving forces of wage inequality this work concentrates on skill-based wage differentials. The pattern of inequality can be decomposed into three main types of inequality: skill-based wage differentials (called college or wage premium); inequality within groups of the same educational level (within group inequality) and age related wage differentials. In general, skill-based inequality could be treated as an indicator of a high demand for high-skilled relative to low-skilled labor. Besides the supply for the different types of labor one has to ask which forces drive the demand for skilled labor possibly generating wage inequality. Numerous attempts have been made to start with this basic approach and to add other forces for inequality.¹

Such approaches can be found, for example, in Katz and Murphy (1992), Krugman (1994), Galor and Tsiddon (1997), Murphy et al. (1998), Goldin and Katz (1998), Katz and Autor (1999), Acemoglu (1998, 2002a,b), Aghion et al. (1999), Krusell et al. (2000), Galor and Moav (2000), Eicher and Peñalosa (2001) and Aghion (2002). The studies by Galor and Tsiddon (1997), Acemoglu (1998) and Galor and Moav (2000) emphasize the general importance of technological change on wage inequality. More particular attempts are undertaken by Galor and Tsiddon (1997) who examine the interaction of technical progress, intergenerational mobility and earnings inequality. They demonstrate that earnings mobility determines the speed of technological change, and therefore economic growth, while technical change determines wage inequality and earnings mobility. Furthermore, Galor and Moav (2000) point to the role of skill biased technical change in explaining the evolution of technology, educational attainment and wage inequality. Our paper is closer to Acemoglu (1998) who emphasizes the importance of high skilled labor in generating technical progress which may lead to both, decreasing wage inequality in the short run and increasing inequality in the long run due to skill-biased technical

¹We want to point out that in this paper we only concentrate on discussion of wage inequality. A more general discussion on growth and income distribution can be found in Greiner et al. (2003).

change.

Although the studies mentioned above are very persuasive either in their empirical or theoretical modelling they almost concentrate on U.S. inequality and their models explain little about factors generating differences across countries. In line of the empirical work by Davis (1992), Berman et al. (1998), Machin and Van Reenen (1998), Haskel and Slaughter (2001) and Acemoglu (2002b), the attempt of our study is to compare, in the context of an endogenous growth model, U.S. and European time series data in order to give an answer why U.S. or U.K. inequality has risen while in Germany or France it has obviously not.

Empirically one has observed that for many countries the number of high skilled workers (e.g. an increasing number of college graduates) have sharply increased over time. Applying a simple 'supply and demand' scheme one should conclude that their wages should decline. However, for some countries this effect has not been observed. There, the wages for skilled people grew more than for less skilled labor. An explanation of the increased inequality is given by the concept of the so-called skill-biased technological change. At least since Goldin and Katz (1998), who presented empirical evidences that physical capital and skills are complements, the argumentation is based on the assumption of some complementarity. If technology grows the demand for skilled labor increases or an increase in the supply of skills induces faster technology growth which leads to an increasing demand for skilled labor, respectively.

An indicator for skill-biased technological change and the demand for skilled labor is the wage- or college premium; the income of high skilled labor relative to wages for workers at a lower skill level. Acemoglu (1998) argues that an increase of supply of skilled labor decreases the wage premium (substitution effect) in the short run. Induced technological change shifts the demand curve to the right and leads to an increase in the wage premium (technology effect).² Such predictions as implied in the model by Acemoglu (1998) has been examined empirically by Katz and Murphy (1992) who estimate parameter values for the U.S. which are in fact close to what Acemoglu's model predicts. However, for other countries, for example E.U. countries, such as France and Germany, we observe different patterns in the development of wage premia. For France it remains almost constant and for West-Germany the wage premium decreases over time using macroeconomic

²See Acemoglu (1998:1057).

time series data. An often noted explanation for the constancy of the European inequality are labor market frictions like the power of trade unions. However, on a disaggregated level (e.g. considering certain industrial sectors) we observe increasing wage inequality for Germany, too (see figure 1).

In this paper, we present a growth model to specify forces generating skill-based wage inequality. Our model is a Romer type growth model which essentially extends the idea of the paper by Murphy, Riddell and Romer (1998). In their paper Murphy et. al. (1998) assume that technical progress leads to wage differentials between high-skilled and unskilled workers. As technical progress occurs, the relative marginal productivity of different inputs change. Yet, if there is sufficient complementarity between skills and new technologies the demand for higher educated labor rises, too, which generates an increase in their wages relative to those of the unskilled workers. Finally, we want to note that in contrast to Krusell, Ohanian and Ríos-Rull (2000) we do not consider substitution between unskilled labor and capital but rather between different types of skill groups.

Employing an innovation - based growth model, which allows for different skill levels in production, wage inequality in our model is determined by the stock of technological knowledge, the relative supply of the skill groups, externalities and substitution effects across different skills. Externalities in our model give rise to wage inequality with the growth of knowledge favoring skilled labor more than unskilled labor. Such a four factor model determining wage inequality is presented and then estimated for U.S. and German time series data. The model and its estimation permits us to discuss why inequality differs across countries.

The remainder of this paper is organized as follows. Section two presents some stylized facts on wage inequality and the supply of skilled labor of main OECD-member countries. Sections three and four develop the determinants of the wage premium based upon our innovation-based growth model. Section five presents estimation results for the U.S. and German time series data. Section six concludes.

2 Some Stylized Facts

Before deriving a theoretical model of wage inequality one should consider some stylized facts on inequality. Figure 1 presents the pattern of wage premia for four OECD - member countries Germany, the U.K., France and the U.S. It should be

mentioned that, in particular, in the case of Germany and the U.S. different measures of wage inequality are compared. Cross-country data of wage differentials are taken from the OECD Employment Outlook (1993, 1996). There, wage inequality is measured by the ratios of the 10th (D1) and 50th (D5) - percentile to the 90th (D9) percentile wage earners.³ Taking into account that the 90th - percentile of the income distribution shows the wages earned by high skilled workers whereas the 10th percentile shows the wages for low skilled workers, it can be shown that the median income of different skill groups increases with the level of education.

For the U.S. and Germany we also employ different sources. Long time series for U.S. wage data are taken from the U.S. Bureau of the Census (1998, 2000). For Germany a separate time series of wage inequality is constructed by taking data of the 'Fachserie 16' published by the Federal Office of Statistics of Germany. There, we compare wages earned by employees at supervisory job position to wage earners at lower job positions.⁴

Considering figure 1 one observes that the D9/D5 - ratios increase moderately or remain constant for each country. Furthermore, the D9/D1 - ratios, regarding the OECD data, increase sharply for the U.S. and the United Kingdom. For Germany one observes a decreasing pattern while for France the D9/D1-ratio remains roughly constant.

Concentrating on Germany and having a look at the data taken from the Federal Statistical Office we observe increasing inequality for the employees in the West German manufacturing sector. In particular, we observe a sharp increase of the wage premium since the middle of the 1990's. For the U.S. considering the Census Bureau data (1998) we observe that until the end of the 1970's the wage premium for college educated workers to non-college education increases slowly. During the 1980's we observe a sharp increase of this ratio while the increase slows down at the beginning of the 1990's.⁵

³See e.g. Katz and Autor (1999) or Murphy et al. (1998) for similar approaches.

⁴It should be mentioned that we concentrate on West German time series data only. Time series data for the unified Germany are not taken into account because of outliers and measurement errors. Furthermore, see Appendix C for our computations.

⁵See Davis (1992) for a brief survey of changes in education differentials during the 1970's and 1980's which is compatible to the results presented in figure 1.

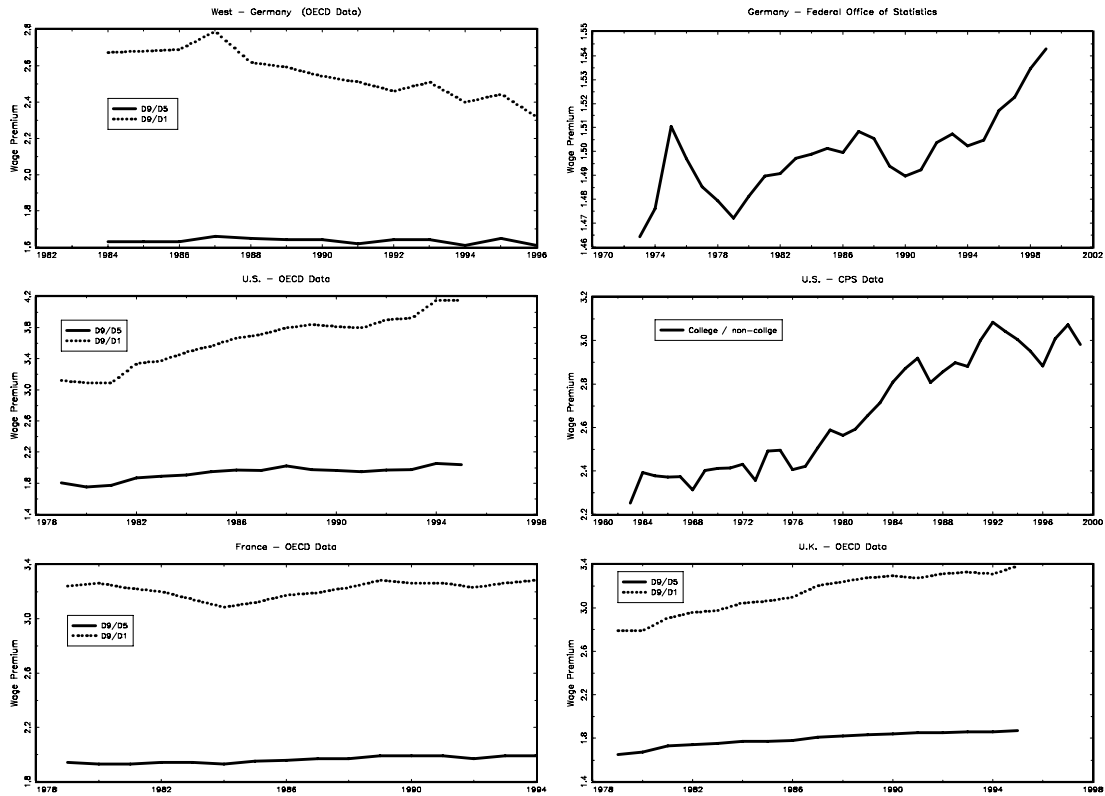


Figure 1: Patterns of Wage Premia

Sources: OECD (1993, 1996), Federal Office of Statistics, Germany, U.S. Bureau of the Census (1998).

Figures 2 and 3 show an increasing fraction of high skilled labor and a declining fraction of workers without college or university education (the ratios are normalized to 1 in 1963 and in 1979, respectively). In particular, we observe that for both countries the fraction of college educated employees has nearly doubled between 1979 and 1999. Figure 2 presents the ratio of college educated workers (bachelor's degree and higher) in percent of total employment for the U.S. (solid line). Figure 3 shows the ratio of university educated employees to total employees for Germany (solid line). The dashed lines of figures 2 and 3 show the fraction of workers without college or university education. For both countries we observe that the fraction of 'low-skilled' workers declines over time.

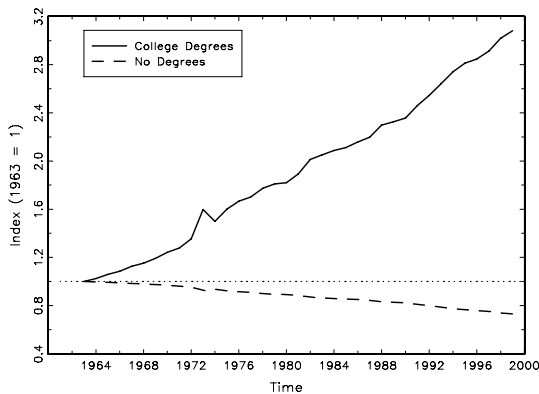


Figure 2: High- and Low Skilled Employment, U.S. 1963-1999 (Index 1963=1).

*Source: U.S. Bureau of the Census
and own calculations*

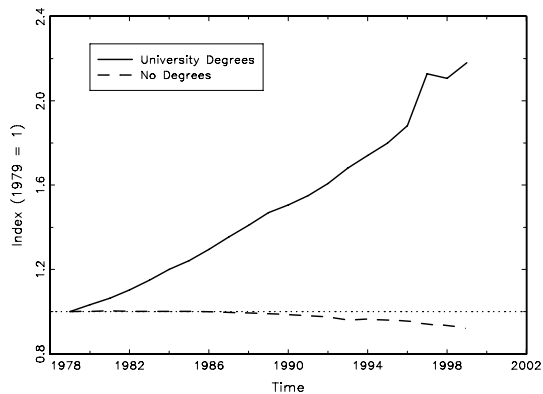


Figure 3: High- and Low Skilled Employment, Germany 1979-1999 (Index 1979=1).

*Source: Federal Office of Statistics
and own calculations*

We can conclude that the above two figures indicate a rising demand for high skilled labor in both countries.⁶ This argument could be related, at least in the case of the U.S., to the increasing wage premium. For Germany this argument does not seem to be convincing because we observe, at least on the aggregate, no increase in the wage premium.

In line with Acemoglu (2002a) one might interpret figures 1, 2 and 3 that there is a shift in the demand curve for skilled labor (skill-biased technological change) in the U.S. On the other hand for the German economy there seems to be less of an increase in inequality at least as far as indicated by our aggregate measures. The following model attempts to explain the above stylized facts in the context of an innovation-based growth model.

3 The Growth Model

Our model is an extension of the approach by Murphy, Riddell and Romer (1998). Yet, we want to note that they do not model their idea in the context of a growth model. To achieve this we start with the Romer (1990) growth model and introduce

⁶See e.g. Katz and Murphy (1992) for a supply and demand explanation of wage inequality.

two groups of households. Additionally, we assume that the number of capital goods, i.e. the designs A , positively affects the efficiency of both unskilled and skilled labor. That is we assume that knowledge capital is associated with positive externalities. We do this because technical progress is embodied in new capital goods. So, the installment of a new machine does not only raise the capital stock but it also increases the productivity of the labor input. That is any worker is expected to produce more output with the new machine compared to the old machine.

The structure of the productive sectors is the same as in the basic Romer (1990) model. So, we will only briefly sketch the derivation of the equations. To integrate our idea into the Romer (1990) growth model, we first have to introduce a modified Cobb-Douglas production function

$$Y = K^{1-\alpha} A^\alpha \eta^{\alpha-1} \left\{ \gamma_1 [A^\xi (H - H_A)]^{\frac{\sigma_p-1}{\sigma_p}} + (1 - \gamma_1) [A^\epsilon L]^{\frac{\sigma_p-1}{\sigma_p}} \right\}^{\frac{\alpha \sigma_p}{\sigma_p-1}}, \quad (1)$$

with K physical capital, H_Y highly qualified employees producing output and H_A highly qualified employees engaged in $R\&D$. $H = H_Y + H_A$ gives the total number of high skilled workers of the economy. L gives the number of low skilled workers who only produce output. $(1 - \alpha) \in (0, 1)$ gives the capital share and α is the labor share. $\sigma_p > 0$, finally, gives the elasticity of substitution between H_Y and L . As in Acemoglu (2002a) we say that skilled and unskilled workers are gross substitutes for $\sigma_p > 1$ and gross complements when $\sigma_p < 1$. ξ and ϵ measure the impact of the external effect, i.e. the impact of technical progress, on H_Y and L . η gives the units of foregone output which are needed to produce one unit of an intermediate good.

Thus, the capital accumulation equation can be written as

$$\dot{K} = K^{1-\alpha} A^\alpha \eta^{\alpha-1} \{X\}^{\frac{\alpha \sigma_p}{\sigma_p-1}} - C, \quad (2)$$

with

$$X = \gamma_1 [A^\xi (H - H_A)]^{\frac{\sigma_p-1}{\sigma_p}} + (1 - \gamma_1) [A^\epsilon L]^{\frac{\sigma_p-1}{\sigma_p}}. \quad (3)$$

The firms in the final good sector behave competitively. The solution to their optimization problem again gives the inverse demand function for the intermediate good $x(i)$. With the production function (1) it follows

$$p(i) = X^{\frac{\alpha \sigma_p}{\sigma_p-1}} (1 - \alpha) K^{-\alpha} \eta^\alpha A^\alpha. \quad (4)$$

The intermediate firm which produces $x(i)$ takes this function as given in solving its optimization problem. The solution to this problem gives the interest rate as

$$r = (1 - \alpha)^2 \eta^{\alpha-1} K^{-\alpha} A^\alpha X^{\frac{\alpha \sigma_p}{\sigma_p - 1}}. \quad (5)$$

Neglecting depreciation of knowledge, the differential equation describing the evolution of the stock of knowledge or the number of designs, A , is given by

$$\dot{A} = \mu H_A^\gamma A^\phi, \quad (6)$$

with $\gamma, \phi \in (0, 1)$.⁷

The differential equation describing the evolution of H_A over time is obtained as follows: First, one uses the fact that the price of knowledge at time t , $P_A(t)$, is equal to the present value of the stream of profits, π , of each intermediate firm because the research sector behaves competitively. This leads to

$$\dot{P}_A = r P_A - \pi, \quad (7)$$

with $\pi = r x \eta \alpha / (1 - \alpha)$. Second, in equilibrium the rental rate of human capital in the final good sector and in the research sector must be equal. This fact gives rise to the following differential equation

$$\begin{aligned} \frac{\dot{P}_A}{P_A} = & \left(\frac{\alpha \sigma_p}{\sigma_p - 1} - 1 \right) \frac{\dot{X}}{X} + (1 - \alpha) \frac{\dot{K}}{K} + \left(\frac{\sigma_p - 1}{\sigma_p} - 1 \right) \frac{\dot{H} - \dot{H}_A}{H - H_A} + \\ & (1 - \gamma) \frac{\dot{H}_A}{H_A} + \left(\alpha - \phi + \xi \frac{\sigma_p - 1}{\sigma_p} \right) \frac{\dot{A}}{A}. \end{aligned} \quad (8)$$

Dividing (7) by P_A , setting the resulting expression equal to (8) and solving for \dot{H}_A

⁷As in Jones (1995) we modify the original knowledge production function of the Romer model in order to eliminate scale effects.

yields

$$\begin{aligned}
\dot{H}_A = & Z^{-1} \cdot \\
& \left[\left(\frac{\gamma}{\gamma_1} \right) (1 - \alpha) \mu X H_A^{\gamma-1} (H - H_A)^{\frac{1+\sigma_p}{\sigma_p}} A^{\phi-1+\xi \frac{1-\sigma_p}{\sigma_p}} - (1 - \alpha) (H - H_A) \frac{C}{K} + \right. \\
& \left(\frac{\sigma_p - 1}{\sigma_p} - 1 \right) g_H H + \left(\alpha - \phi + \xi \frac{\sigma_p - 1}{\sigma_p} \right) \mu H_A^\gamma A^{\phi-1} (H - H_A) + X^{-1} \cdot \\
& \left(\frac{\alpha \sigma_p}{\sigma_p - 1} - 1 \right) \frac{\sigma_p - 1}{\sigma_p} \gamma_1 (A^\xi (H - H_A))^{\frac{\sigma_p-1}{\sigma_p}} \cdot \left(\xi \mu H_A^\gamma A^{\phi-1} (H - H_A) + H g_H \right) \\
& + (H - H_A) \alpha (1 - \alpha) \eta^{\alpha-1} K^{-\alpha} A^\alpha X^{\alpha \sigma_p / (1 - \sigma_p)} + \\
& X^{-1} \left(\frac{\alpha \sigma_p}{\sigma_p - 1} - 1 \right) \frac{\sigma_p - 1}{\sigma_p} (1 - \gamma_1) (A^\xi L)^{\frac{\sigma_p-1}{\sigma_p}} (H - H_A) \cdot \\
& \left. (\epsilon \mu H_A^\gamma A^{\phi-1} + g_L) \right], \tag{9}
\end{aligned}$$

with $Z = \left(\frac{\sigma_p-1}{\sigma_p} \right) - (1 - \gamma) \frac{H-H_A}{H_A} + \gamma_1 \left(\frac{\sigma_p-1}{\sigma_p} \right) X^{-1} \left(\frac{\alpha \sigma_p}{\sigma_p-1} \right) (A^\xi (H - H_A))^{\frac{\sigma_p-1}{\sigma_p}}$. g_H and g_L give the growth rate of the total stock of human capital or skilled labor H and the growth rate of low skilled labor L , i.e.

$$\dot{H} = H g_H, \tag{10}$$

$$\dot{L} = L g_L. \tag{11}$$

The model is completed by modelling the household sector. This sector consists of a representative household which supplies skilled labor, H , and unskilled labor, L . The optimization problem of the household is given by

$$\max_C \int_0^\infty e^{-\rho t} u(C(t)) dt. \tag{12}$$

subject to the budget constraint.

The optimization problem gives the growth rate of consumption as

$$\frac{\dot{C}}{C} = -\frac{\rho - r}{\sigma}, \tag{13}$$

with $1/\sigma$ the constant intertemporal elasticity of substitution of consumption between two points in time, and ρ is the subjective rate of time preference of the household.

Our economy is completely described by equations (2), (6), (9), (10), (11) and (13), with the interest rate r given by (5). In the following we will focus on the

wage premium, i.e. the ratio of the wages earned by high-skilled workers to those of low-skilled workers, and derive implications of our model for this variable on the Balanced Growth Path (BGP).

For this model a BGP is derived as for the semi-endogenous growth model with R&D as in Jones (1995). We define a BGP as a path with a constant output/capital ratio, Y/K , and where all variables grow at constant but not necessarily equal rates. This implies

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

Using $d/dt(\dot{A}/A) = 0$ and $d/dt(\dot{K}/K) = 0$ yields $\frac{\dot{A}}{A} = \frac{\gamma}{1-\phi} g_{H_A}$, $\frac{\dot{K}}{K} = \frac{\gamma}{1-\phi} g_{H_A} + \frac{\sigma_p}{\sigma_p-1} \frac{\dot{X}}{X}$, where we define $g_{H_A} = \dot{H}_A/H_A$. If the growth rates of A and H_Y are constant it can easily be shown that the following relation holds concerning the growth rate of X ,

$$\lim_{t \rightarrow \infty} \frac{\dot{X}}{X} = \frac{\sigma_p - 1}{\sigma_p} (\xi g_A + g_{H_Y}), \quad \text{for } (\epsilon g_A + g_L) \leq (\xi g_A + g_{H_Y}).$$

The condition $(\epsilon g_A + g_L) \leq (\xi g_A + g_{H_Y})$ does not pose a sincere limitation of our model. This holds because, on the one hand, the growth rate of high skilled labor in the final goods sector, g_{H_Y} , has been larger than the growth rate of unskilled labor, g_L , in the industrialized countries in the recent decades. Further, on the other hand, it is to be expected that the external effect associated with new machines, i.e. with a rise in A , is higher for skilled labor than for unskilled labor, implying $\xi > \epsilon$.

Moreover, dividing (7) by P_A and setting it equal to (8) shows that on a BGP H_A and H_Y must grow at the same rate.⁸ This fact together with the condition $H_A + H_Y = H$ implies that H also grows at the rate with which H_A and H_Y grow on the BGP, i.e. we have $g_{H_A} = g_{H_Y} = g_H$. Thus, on a BGP we have

$$\frac{\dot{K}}{K} - g_H - g_L = g_H \frac{\gamma}{1-\phi} (1 + \xi) - g_L. \quad (14)$$

This equation demonstrates that a sufficient and necessary condition for the growth rate of aggregate variables to exceed the growth rate of skilled and unskilled labor is

$$g_H \frac{\gamma}{1-\phi} (1 + \xi) > g_L. \quad (15)$$

⁸It can be shown that for $(\epsilon g_A + n) > (\xi g_A + g_{H_Y})$ no BGP with constant and positive per capita growth rate exists.

If the growth rate of human capital equals zero this model does not yield sustained per capita growth in the long run, just as the modified Romer model. Then, on the BGP aggregate output, aggregate physical capital and aggregate consumption grow at the same rate as labor input implying that per capita variables are constant. Looking at equation (15) one realizes that this condition is more likely to be fulfilled the more productive human capital in the research process is, i.e. the higher γ , and the larger the positive externality of new designs, i.e. the higher ξ .

However, sustained per capita growth only occurs if the growth rate of human capital is positive, that is if $g_H > 0$. Thus, we get a semi-endogenous growth model where conventional government policies cannot affect the long run balanced growth rate. In the next section we will discuss the implications of this model as to the wage premium assuming competitive labor markets.

4 The Wage Premium

The wage premium is defined as the ratio of the wages earned by high-skilled workers and the wages earned by low-skilled workers. This variable is of potential interest to economists because it can be seen as a measure of the flexibility of the labor market which has repercussions for the unemployment rate in an economy.⁹ Further, the wage premium reflects the inequality between high-skilled and low-skilled workers. If the wage premium rises, the gap between employees getting high wages and employees getting low wages widens which tends to make the income distribution more unequal. If the wage premium falls the reverse holds.

As concerns the determination of the wage premium it is affected by two factors. First, an increase in the supply of high-skilled workers reduces the wage rate for this kind of work and tends to reduce the wage premium. Second, a rise in the number of skilled workers implies that the profitability of technologies increases which are complementary to skilled labor (cf. Acemoglu, 1998). This has a positive effect on the wages of high-skilled workers and, consequently, raises the wage premium. It should be noted that the increase in the supply of high-skilled workers may be the result of government policies. If a government decides to raise the expenditures for education the number of high-skilled workers is expected to rise over time. If it

⁹For a detailed study on the effect of wage inequality on unemployment, see Nickel (1997). Of course, in our model we do not explicitly take into consideration unemployment.

reduces public spending for education, the converse holds.

To derive the wage premium in our model we recall that the production function is given by

$$Y = K^{1-\alpha} A^\alpha \eta^{\alpha-1} \{X\}^{\frac{\alpha \sigma_p}{\sigma_p-1}}, \quad (16)$$

with $X = \gamma_1 [A^\xi (H - H_A)]^{\frac{\sigma_p-1}{\sigma_p}} + (1 - \gamma_1) [A^\epsilon L]^{\frac{\sigma_p-1}{\sigma_p}}$ and $H - H_A = H_Y$. If we assume competitive markets, the wages of high and low qualified employees are equal to the marginal products of high and low qualified workers in the production sector. This gives

$$w_H = \alpha \gamma_1 \eta^{\alpha-1} K^{1-\alpha} A^\alpha X^{\frac{\alpha \sigma_p}{\sigma_p-1}-1} A^{\frac{\xi(\sigma_p-1)}{\sigma_p}} H_Y^{-\frac{1}{\sigma_p}}, \quad (17)$$

$$w_L = \eta^{\alpha-1} \alpha (1 - \gamma_1) K^{1-\alpha} A^\alpha X^{\frac{\alpha \sigma_p}{\sigma_p-1}-1} A^{\frac{\epsilon(\sigma_p-1)}{\sigma_p}} L^{-\frac{1}{\sigma_p}}. \quad (18)$$

The ratio of the marginal products of the two types of labor, the wage premium w_p , is given by:

$$w_p \equiv \frac{w_H}{w_L} = \frac{\gamma_1}{1 - \gamma_1} \left[\frac{A^\xi}{A^\epsilon} \right]^{\frac{\sigma_p-1}{\sigma_p}} \left[\frac{H_Y}{L} \right]^{-\frac{1}{\sigma_p}} \quad (19)$$

This result is similar to the one obtained in the paper by Murphy, Riddell and Romer (1998)¹⁰

$$\tilde{w}_p = c \left[\frac{A(t)}{B(t)} \right]^{\frac{\sigma_p-1}{\sigma_p}} \left[\frac{H}{L} \right]^{-\frac{1}{\sigma_p}}, \quad (20)$$

where c denotes a positive constant, σ_p is the elasticity of substitution between high- and low-skilled workers, $A(t)$ and $B(t)$ are levels of technological knowledge available to high and low skilled workers. The main differences between equations (19) and (20) are that in our model there exists only one stock of technological knowledge which is available to any worker. Furthermore, equation (19) assumes an external effect of technical change ($\xi - \epsilon$).

Defining

$$A_{w_p} \equiv \frac{A^\xi}{A^\epsilon}, \quad L_{w_p} \equiv \frac{H_Y}{L}, \quad (21)$$

we can derive a differential equation describing the evolution of the ratio w_p which is

$$\frac{\dot{w}_p}{w_p} = \left(\frac{\sigma_p - 1}{\sigma_p} \right) \frac{\dot{A}_{w_p}}{A_{w_p}} - \left(\frac{1}{\sigma_p} \right) \frac{\dot{L}_{w_p}}{L_{w_p}}. \quad (22)$$

¹⁰See Murphy et al. (1998:294).

From the definitions of A_{w_p} and L_{w_p} we get

$$\frac{\dot{A}_{w_p}}{A_{w_p}} = (\xi - \epsilon) \frac{\dot{A}}{A} \quad \text{and} \quad \frac{\dot{L}_{w_p}}{L_{w_p}} = \frac{\dot{H}_Y}{H_Y} - \frac{\dot{L}}{L}. \quad (23)$$

Considering the wage premium, equation (19), we see that four main factors determine this variable.

First, the quotient of the productivity parameters $\gamma_1/(1 - \gamma_1)$. If γ_1 is very small and close to zero the wage premium will have a small value, too. A small value for γ_1 means that the productivity of the high-skilled workers relative to the low-skilled workers is small, i.e. low-skilled workers contribute more to the output than high-skilled workers. Consequently, the wage of the low-skilled workers is relatively high and the wage premium is relatively low. If γ_1 is large, say near to one, the reverse holds. That is the productivity of the high-skilled workers is relatively high and, as a consequence, their wage rate and the wage premium are high, too.

Second, the ratio A^ξ/A^ϵ affects the wage premium. A high (low) value for ξ relative to ϵ means that the positive external effect of technical change affects high-skilled workers to a greater (lower) degree compared to low-skilled workers. That is, technical change, an increase in A , leads to a stronger (smaller) increase in the productivity of high-skilled workers compared to low-skilled workers. As a consequence, the larger the positive difference $\xi - \epsilon$ the higher the wage premium, provided skilled and unskilled labor are gross substitutes, i.e. for $\sigma_p > 1$.¹¹ Further, in this case technical change, i.e. an increase in A , raises the wage premium. If skilled and unskilled labor are gross complements ($\sigma_p < 1$) technical change, i.e. an increase in A , leads to a decline in the wage premium. This holds because in this case skilled and unskilled labor are gross complements and, therefore, the relative increase in the labor productivity of skilled labor also raises the demand for unskilled labor, where the latter increase exceeds the increase in demand for skilled labor.

Third, the number of high-skilled workers relative to the number of low-skilled workers determines the wage premium. If this ratio is high the supply of high-skilled workers is relatively large. As a consequence, the wage premium will take on a low value.

The fourth factor which affects the wage premium is the elasticity of substitution

¹¹Note that in this model, in contrast to Acemoglu (2002a), the value of σ_p is not the only factor determining the technology - skill complementarity, i.e. the difference of ξ and ϵ increases or dampens the influence of σ_p .

between high-skilled and low-skilled workers, σ_p . To find the effect of σ_p on the wage differential we rewrite (19) and get

$$w_p = \frac{w_H}{w_L} = \frac{\gamma_1}{1 - \gamma_1} A^{\xi - \epsilon} \left[A^{\epsilon - \xi} \left(\frac{L}{H_Y} \right) \right]^{\frac{1}{\sigma_p}}. \quad (24)$$

Differentiating (24) with respect to σ_p gives

$$\frac{\partial(w_H/w_L)}{\partial\sigma_p} = -\frac{\gamma_1}{1 - \gamma_1} A^{\xi - \epsilon} \left[A^{\epsilon - \xi} \frac{L}{H_Y} \right]^{\frac{1}{\sigma_p}} \sigma_p^{-2} \ln \left[A^{\epsilon - \xi} \left(\frac{L}{H_Y} \right) \right]. \quad (25)$$

This expression is positive (negative) for $A^{\epsilon - \xi}(L/H_Y) < (>) 1$. This implies that a higher elasticity of substitution raises (reduces) the wage differential if the ratio (L/H_Y) is relatively large (small), i.e. if it is larger (smaller) than the threshold level $A^{\xi - \epsilon}$. That means if the supply of unskilled workers is relatively high an increase in the elasticity of substitution between high-skilled and low-skilled workers raises the wage differential. If the supply of unskilled workers is low a higher elasticity of substitution between high-skilled and low-skilled workers reduces the wage differential.

The growth rate of the wage differential is given by equation (19) together with (22) and (23). It crucially depends on the elasticity of substitution between high-skilled and low-skilled workers, i.e. on σ_p . The effect of σ_p on the growth rate of the wage differential is obtained by differentiating (22) with respect to σ_p . This gives

$$\frac{\partial(\dot{w}_p/w_p)}{\partial\sigma_p} = \frac{1}{\sigma_p^2} \left[\frac{\dot{A}_{w_p}}{A_{w_p}} + \frac{\dot{L}_{w_p}}{L_{w_p}} \right]. \quad (26)$$

If the sum in brackets is positive an increase in the elasticity of substitution raises the growth rate of the wage differential. This means the difference between high-skilled and low-skilled wages rises with a higher elasticity of substitution provided the term in brackets is positive. This latter expression is composed of two parts. First, the difference between the growth rates of the labor productivity of high-skilled and low-skilled workers. A positive difference tends to make the expressions in brackets positive. Second, the difference between the growth rates of high-skilled workers and low-skilled workers. If this expression is positive the term in brackets tends to be positive, too.

Thus, we can state that an increase in the elasticity of substitution between high- and low-skilled workers raises the wage differential if the growth rate of productivity

of high-skilled workers (as a result of positive externalities of physical capital) is larger than the one of low-skilled workers and if the growth rate of high-skilled labor exceeds the growth rate of low-skilled labor. For example, if high-skilled and low-skilled labor grows at the same rate only the growth rate of the labor productivity of the two groups affects equation (26). Then the growth rate of the wage differential is the higher the higher the elasticity of substitution between high-skilled and low-skilled workers, provided the labor productivity of high-skilled workers grows faster than the labor productivity of low-skilled workers. If the labor productivity of the low-skilled workers grows faster than the one of the high-skilled the reverse holds. Then, an increase in the elasticity of substitution reduces the growth rate of the wage differential, i.e. the difference between high-skilled and low-skilled wages becomes smaller over time.

Further, it is easily seen that $\xi > \epsilon$ implies that the wage differential rises and vice versa, if skilled and unskilled labor grow at the same rate and if skilled and unskilled labour are gross substitutes, i.e. for $\sigma_p > 1$. This makes sense from the economic point of view, because $\xi > (<)\epsilon$ means that the labor productivity of skilled labor grows faster (slower) than that of the unskilled workers. If $\xi = \epsilon$ only the growth rates of skilled and unskilled labor supply affect the growth rate of the wage premium. If skilled labor grows faster (slower) than unskilled labor the wage premium falls (rises) which is reasonable from an economic point of view. Thus, technical progress may drive a wedge between the income of well qualified and less qualified workers making the income distribution more unequal over time. This result is close to the model of Aghion (2002). There, the increase in wage inequality depends crucially on the diffusion of so-called General Purpose Technologies (GPT) and phases of innovation. In a first phase, researchers are less productive than ‘normal’ workers but if the new technology diffuses researchers or high skilled people become more productive than lower skilled workers. In this work, a similar effect is captured by the sign of the difference between ξ and ϵ .

Now, one can identify four influences determining the wage premium:

1. the growth of knowledge, g_A

This variable represents the effects of an economywide stock of knowledge on the wage premium.

2. the growth rate of the supply of the two types of labor, g_H, g_L
This effect indicates how the relative supply of each kind of workers affect the wage premium.
3. the technology effect
The technology effect is driven by the sign of $(\xi - \epsilon)$. $\xi > \epsilon$ implies that the productivity of high-skilled workers raises stronger than that of low-skilled workers if technical progress occurs. If skilled and unskilled labour are gross substitutes, i.e. for $\sigma_p > 1$, this leads to a higher demand for skilled workers which increases the wage differential.
4. the elasticity of substitution:
The elasticity of substitution between high and low skilled workers measures the effect how high skilled workers can be replaced by low skilled ones.

Referring to equations (19) and (22) the main parameters of interest are the elasticity of substitution and the technology effect. Knowledge about the sign and values of these parameters allows for a better understanding of the forces driving the different patterns of wage inequality. Taking logs of equation (19) and differentiating with respect to time we obtain the growth rate of the wage premium:

$$\hat{w}_p = \frac{\dot{w}_p}{w_p} = \left(\frac{\sigma_p - 1}{\sigma_p} \right) (\xi - \epsilon) g_A - \frac{1}{\sigma_p} (g_H - g_L), \quad (27)$$

where $g_A = \frac{\dot{A}}{A}$, $g_H = \frac{\dot{H}_Y}{H_Y}$ and $g_L = \frac{\dot{L}}{L}$. Now, equation (27) allows for a closer examination of the technology effect and of the value of the elasticity of substitution. The following section presents time series data and estimations for two OECD - member countries, Germany and the U.S.

5 Data and Estimation

5.1 Data Sources and Computations

Our main data sets applied in this study come from the Federal Office of Statistics (Germany) and the U.S. Bureau of the Census, (U.S.). Our data are different, yet compatible, to the data published by the OECD (1994,1996) or applied by Acemoglu (2002b). We prefer our data set because it allows us to work with consistent time series data over a longer time horizon.

Considering equation (27) we need data for H_Y , L and A . H_Y represents employed civilian labor force at a higher educational level for example which have earned a college degree (bachelor's degree and higher). L denotes the number of employees at a lower educational level. For the U.S. the data are taken from the Annual Statistical Abstract (various issues since 1965) and the U.S. Bureau of the Census (1998, 2000). The German Series are taken from the Federal Statistical Office (1978-2000). The time series of median wages and wage dispersions are taken from the U.S. Bureau of the Census (1998, 2000) and from the 'Fachserie 16' published by the Federal Statistical Office of Germany. We have to point out that the applied German data represent only wages and numbers employees of the West German manufacturing sector.¹²

A primary problem is to construct a reliable measure of the stock of knowledge A . In particular, various measures of a stock of knowledge exist.¹³ A measure of a stock of knowledge should include innovative investments, a measurable output of knowledge production and the flow of information on knowledge. As an approximation of the first two measures we take R&D - investment and the number of national patent grants. The third item is difficult to approximate. It could include trade flows of technology, the number of internet connections or the number of scientific workshops and conferences. To be consistent with the model of section 4 a closed economy without foreign trade is assumed. Furthermore, taking the growing number of internet connections into account one might assume that the information flow across industrialized countries like U.S. and Germany is the same. Therefore, we apply three different approximations of the 'growth rate of knowledge' in our estimations. First, we take the growth rate of total R&D - Expenditures per GDP. Second, we constructed a series by calculating the mean growth rate of the R&D intensity and the growth rate of national patent grants. This measure represents an inventive input (R&D Expenditures) and a possible output of such investments.¹⁴ Our third method builds on Coe and Helpman (1995) and Gong et al. (2001), who constructed a stock of knowledge by applying the perpetual inventory method.¹⁵ In

¹²Note, however, that the manufacturing sector represents in Germany a large fraction of the GDP, roughly 50 percent.

¹³See e.g. Gong et al. (2001) or OECD (1996), for an appropriate overview.

¹⁴See Siegel (1999) for a brief survey of similar measures of approximating the stock of knowledge or Machin and van Reenen for the use of R&D Expenditures as a proxy of technical change.

¹⁵See Appendix B for a brief description of the perpetual inventory method.

this case the stock of knowledge A is approximated through cumulated real R&D - expenditure. The following table summarizes the construction of our time series data:

Table 1: Data Computations

Variable	Data
\hat{w}_p	Growth Rate of Wage Differentials growth rate of R&D - Intensities
g_A	mean growth rate of R&D Intensity and Patents growth rate of the Stock of Knowledge (A)
g_H	Employees with college or higher education
g_L	Employees without college or higher education

Before concentrating on the parameter estimations we present some main properties of our constructed time series data. For the U.S. we concentrate on two different kinds of wage premia. First, we calculate the wage premium of employees with college education to employees without college education. This time series is called ‘wage premium’. Secondly, we calculate a series where we compare the wages of employees with some college degree over employees with high school education. According to Murphy et. al. (1998) we call this series ‘college premium’. Table 2 shows some characteristics of the applied U.S. data. It should be noted that, according to table 1 and eqn. (27), each variable is measured in growth rates.

Table 2: Time Series Properties, U.S. Data (1964-99)

Variable	Mean	Std. Dev.
Wage Premium	0.0078	0.0258
College Premium	0.0089	0.0226
$\frac{\text{bach. degree}}{\text{no bach.}}$	0.0400	0.0377
$\frac{\text{bach. degree}}{\text{high school}}$	0.0215	0.0277
R&D - Intensity	-0.0005	0.0306
R&D + Patents	0.0110	0.0360
Stock of Knowl. (A)	0.0262	0.0081

For the U.S. we observe a small mean growth rate of the wage and college premia.

Furthermore, the growth rate of technological change seems to be small, too. The mean growth rate of A and the ratios of high-skilled labor to the labor with lower skills (see line 4 and 5) are positive too.

Comparing the results for the U.S. with the German data (see table 3) we observe that the mean growth rate of wage inequality is in the U.S. four times higher than in Germany. Furthermore, table 3 shows that the mean growth rate of the R&D - Intensity is low, in the case of the U.S. it is negative. Yet, for both countries we observe growth rates of A significantly positive. It is interesting to note that for most of the variables the U.S. time series exhibit a higher standard deviation. This, in particular holds for the wage premium, apparently reflecting the well known differences in the mobility of labor of the two countries.

Table 3: Time Series Properties, German Data (1974-98)

Variable	Mean	Std. Dev.
Wage Premium	0.0019	0.0068
$\frac{\text{higher Educ.}}{\text{lower Educ.}}$	0.0111	0.0231
R&D Intensity	0.0028	0.0365
R&D + Patents	0.0098	0.0192
Stock of Knowl. A	0.0431	0.0139

5.2 Estimation Results

Before we estimate the parameters of the equation giving the wage premium, we want to examine simple correlations between the wage premium and the main variables such as the stock of knowledge and the relative supply of skilled workers. We employ simple OLS regressions for the wage premium and the other variables. The results are illustrated in appendix A and summarized in table 4. As one would expect most of our proxies of knowledge show a positive influence of knowledge on the wage premium. This seems to hold for the U.S. as well as for Germany. Results of the literature on skill-biased technological change seem to be supported by the results of table 4. On the other hand whereas the relative increase of high skilled labor, compared to low skilled labor, does not make the wage premium for the U.S. falling - but rather rising - for Germany one can observe the opposite result.

Table 4: Sign of Correlations

Country	Variable			
	R&D Intensity	R&D + Patents	g_A	$g_H - g_L$
U.S. Wage Premium	+	+	+	+
U.S. College Premium	+	+	+	+
Germany Wage Prem.	+	+	-	-

The results of table 4 indicates positive technology effects and, except for the U.S., negative supply effects. Therefore, we conclude that in the U.S. skilled workers are more scarce compared to unskilled workers which gives rise to an increasing wage premium in contrast to Germany.

Next we estimate the parameters of the wage premium, given by equation (27). Because of the structure of equation (27) it seems sufficient to apply OLS estimation in a first step. Consistent with the equation (27) and the work of Katz and Murphy (1992) and Murphy, Riddell and Romer (1998) the following regression equation is estimated

$$\hat{w}_p = \beta_1 + \beta_2 g_A - \frac{1}{\beta_3} g_{HL} + \varepsilon \quad (28)$$

where $g_A = \frac{\dot{A}}{A}$ and $g_{HL} = (g_{H_Y} - g_L)$. Mention that β_1 represents an arbitrary constant which captures other variables influencing the wage premium (e.g. the role of trade unions). The parameters β_2 and β_3 represent the so called technology effect and the elasticity of substitution.¹⁶ In the first step, not reported here, we have employed OLS regressions. For almost all of the regressions for both the U.S. as well as Germany we obtained the expected sign but the parameters were insignificant. As one can observe from the plots of appendix A the time series are characterized by strong outliers. We, therefore, undertook regressions by a procedure that gives less weight to outliers. We employed a nonlinear estimation technique that gives higher weight for values close to the mean and a lower weight for values far from it. We obtained the following results for the U.S.:

¹⁶Note that β_2 represents:

$$\beta_2 = \frac{\sigma_p - 1}{\sigma_p} (\xi - \varepsilon) \Rightarrow (\xi - \varepsilon) \approx \frac{\beta_3}{(\beta_3 - 1)} \beta_2$$

Table 5: Estimation of Eq (28), U.S. (1964-99)

	<i>U.S. Wage Premium</i>			<i>U.S. College Premium</i>		
Proxy for Knowl.	β_1	β_2	β_3	β_1	β_2	β_3
R&D - Intens.	0.0207	0.0720	2.7716	0.0166	0.2959	2.6621
<i>std. error</i>	0.0069	0.1586	0.9879	0.0574	0.1375	1.3149
R&D + Patents	0.0212	0.0066	2.7229	0.0169	0.1645	2.6602
<i>std. error</i>	0.0071	0.1330	0.9412	0.0062	0.1256	1.4131
A	0.0177	0.1278	2.7506	0.0118	0.2226	2.8822
<i>std. error</i>	0.0177	0.5936	0.9698	0.0189	0.6125	1.8292

As one can observe the regression coefficients have the expected sign and most of them are significant. The results for the German economy are presented in table 6.

Table 6: Estimation of Eq (28), Germany (1974-98)

Approx. of Knowl.	β_1	β_2	β_3
R&D - Intens.	0.0097	0.1271	1.7536
<i>std. error</i>	0.0019	0.0475	0.2505
R&D + Patents	0.0122	-0.1139	1.6965
<i>std. error</i>	0.0024	0.0595	0.2586
A	0.0067	0.2165	1.9261
<i>std. error</i>	0.0022	0.0940	0.3143

Here, almost all parameters have the expected sign and are significant. The main difference between the results for the U.S. and Germany is that for Germany the elasticity of substitution is lower than for the U.S. which has dampening effects on the growth rate of the wage premium (see eqn (26)).

For both countries we obtain almost significant results for β_1 . This result shows that technology and the substitution between skilled and low skilled workers are, of course, not the only forces determining wage inequality. There are possibly other forces which may explain the positive constant β_1 . In particular, for Germany labor market institutions like trade unions and wage negotiations are not included in our regressions. We do not neglect the role of such institutions, but, because of our

attempt to use time series data, i.e. growth rates, the impact and quantification of such labor market institutions is extremely difficult.¹⁷

In both countries the knowledge variable has a positive effect and a larger growth rate of skilled compared to unskilled labor has a negative effect on the wage premium. On the other hand, the value the elasticity of substitution between the two types of labor takes also affects the growth rate of the wage premium besides the growth rates of the supply of skilled and unskilled labor. The higher the elasticity of substitution between the two types of labor the higher the growth rate of the wage premium, given that the sum of the other two effects in equ. (26) is positive.¹⁸

6 Conclusion

In the paper we have shown that there are four main factors driving wage inequality. These are the rate of technological change, the technological spill-over effect, the relative supply of skilled and unskilled labor and the elasticity of substitution between high and low skilled workers. If technical change, the technological spill-over effect and the growth rate of the ratio of skilled to unskilled labor are given and positive then the elasticity of substitution may mitigate wage inequality. With a low elasticity of substitution the growth rate of the wage inequality is small and may be even negative if the growth rate of the ratio of skilled to unskilled labor is positive and if there is skill biased technical change. With a high elasticity the wage inequality is less corrected. Thus, the increase in wage inequality is strongly mitigated if the elasticity of substitution is low and the growth rate of skilled compared to unskilled labor is higher.

Both our model and our estimates for the U.S. time series data allow a coherent interpretation of the trends in wage inequality. In the case of the U.S. the elasticity of substitution is greater than one but lower than for Germany. For Germany, the stylized facts show that there is less wage inequality and if there is, one can observe that the reduction of inequality arising from a positive growth rate of skilled to

¹⁷Applying the labor market institutions Database from Nickell et al. (2001), we observed nearly no variations in the data. Therefore, because of the constancy of the time series data we can obtain no further insights compared to our results as reported in tables 5 and 6. What, however, likely is that unionization has an impact on the constant term in our regression.

¹⁸This is consistent with results in resource economics where the scarce resource obtains overtime the larger income share the smaller the elasticity of substitution between inputs is, see Scholl and Semmler (2000).

unskilled labor is mitigated by the lower elasticity of substitution. Yet, we want to point out, that in Germany there appear to be also other forces, for example, the influence of the trade union wage setting policies, that have reduced wage inequality over time. We have not taken into account those forces which may also explain part of the trend in the wage premium, particularly for Germany. As the stylized facts in section 2 showed it is only in recent times that wage inequality tends to rise in Germany.

So far we have only discussed inequality across skill groups. Within group inequality describes the observation that wages earned by workers with the same qualification are not the same. Aghion et al. (1999), for example, apply a model with vintage capital and learning by doing effects. There, it is assumed that new capital goods have positive effects on the productivity of workers. The workers can either improve their knowledge through learning activities or remain at the same job. As a result workers become more heterogeneous which leads to increasing wage differentials within groups of similar skill levels.

Another important influence for increasing wage inequality is assumed to arise from international trade. In particular, if an industrialized country increases its exports of skill-intensive goods and raises its imports of labor intensive goods, the production will shift to skill intensive goods which raises the skill-based wage inequality. In the long-run the rising wage inequality will lead to a reduction of the ratio of high skilled to low skilled workers. However, Krugman (1994) argues that if trade liberalization is the main force behind growing wage inequality this would lead to two observable facts: first a declining ratio of skilled to unskilled employment and, secondly, a substantial shift of employment towards skill intensive industries. Krugman (1994) argues further, that both propositions fail to hold and that wage differentials and the relative demand for skilled people has increased because of some *“common factors that affect all sectors”*.¹⁹

Although aggregated data are employed in our study, some main influences on the observed patterns of wage inequality could be quantified. Further work with disaggregated data sets or more precise assumption about the wage setting behavior is left for future research.

¹⁹See Krugman (1994:36).

Appendix A: Correlations

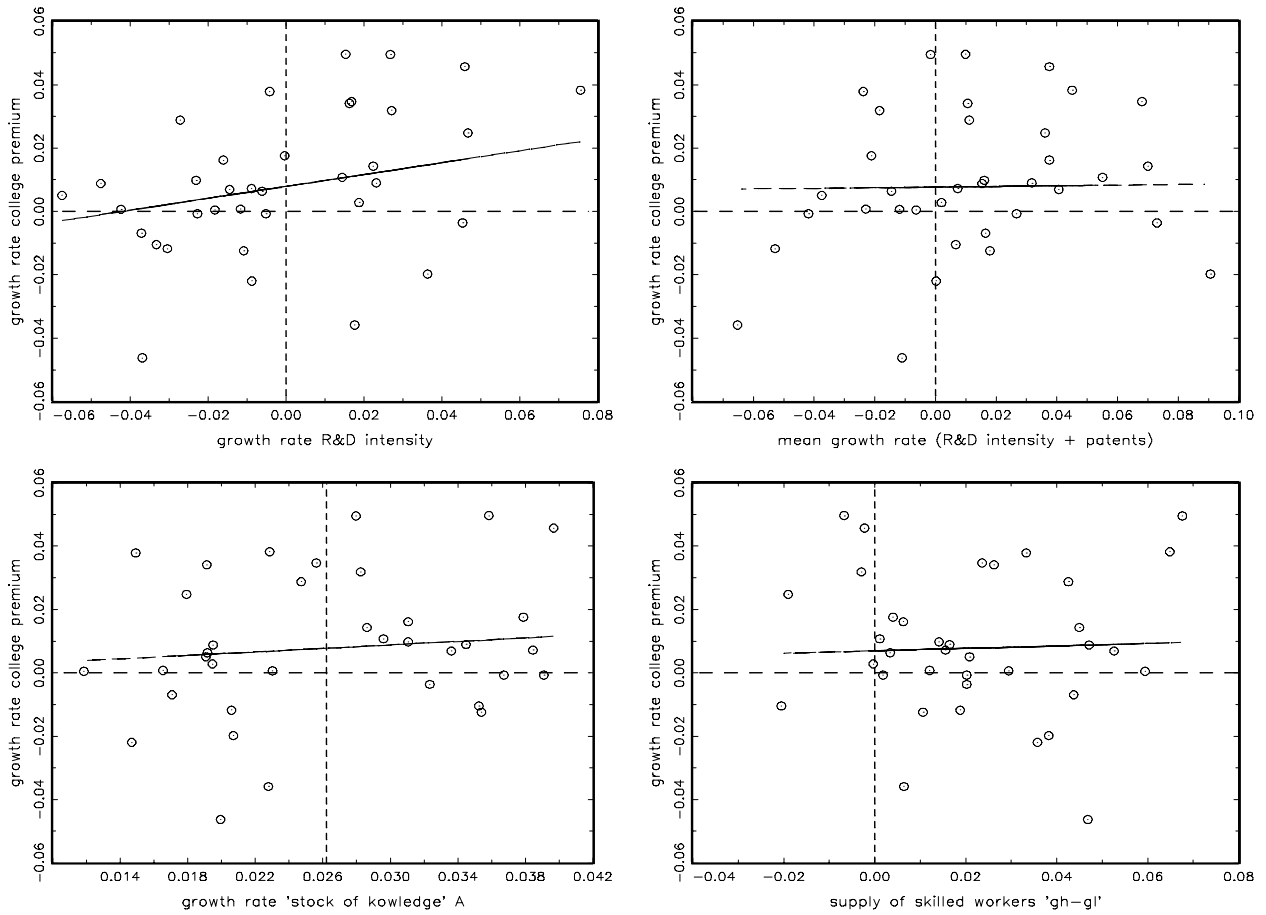


Figure 4: Correlation US - College Premium (1964-99)

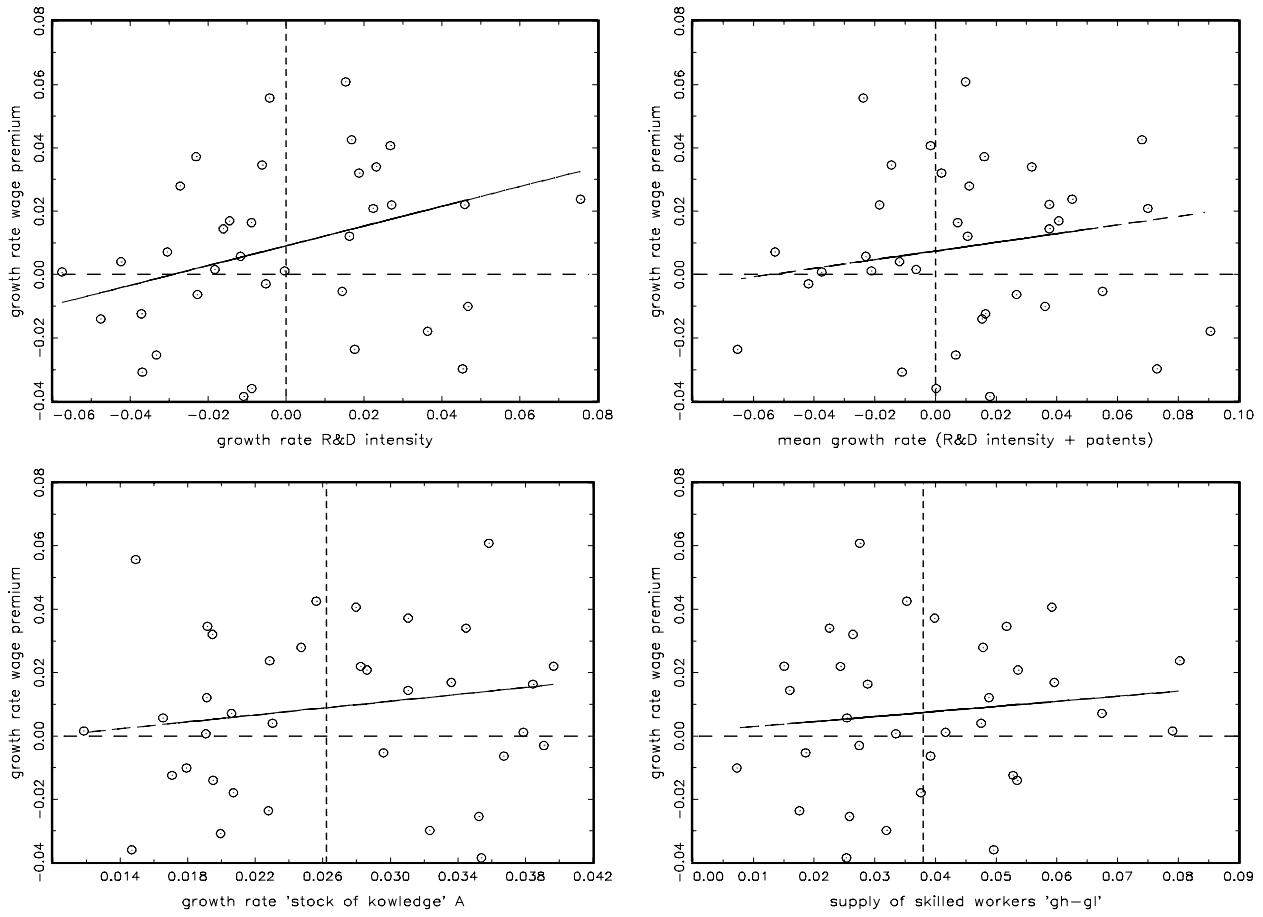


Figure 5: Correlation US - Wage Premium (1964-99) ²⁰

²⁰Note that the 'largest' outliers of the data of figure 5 (low right) are truncated. Including those observations we would observe no correlation.

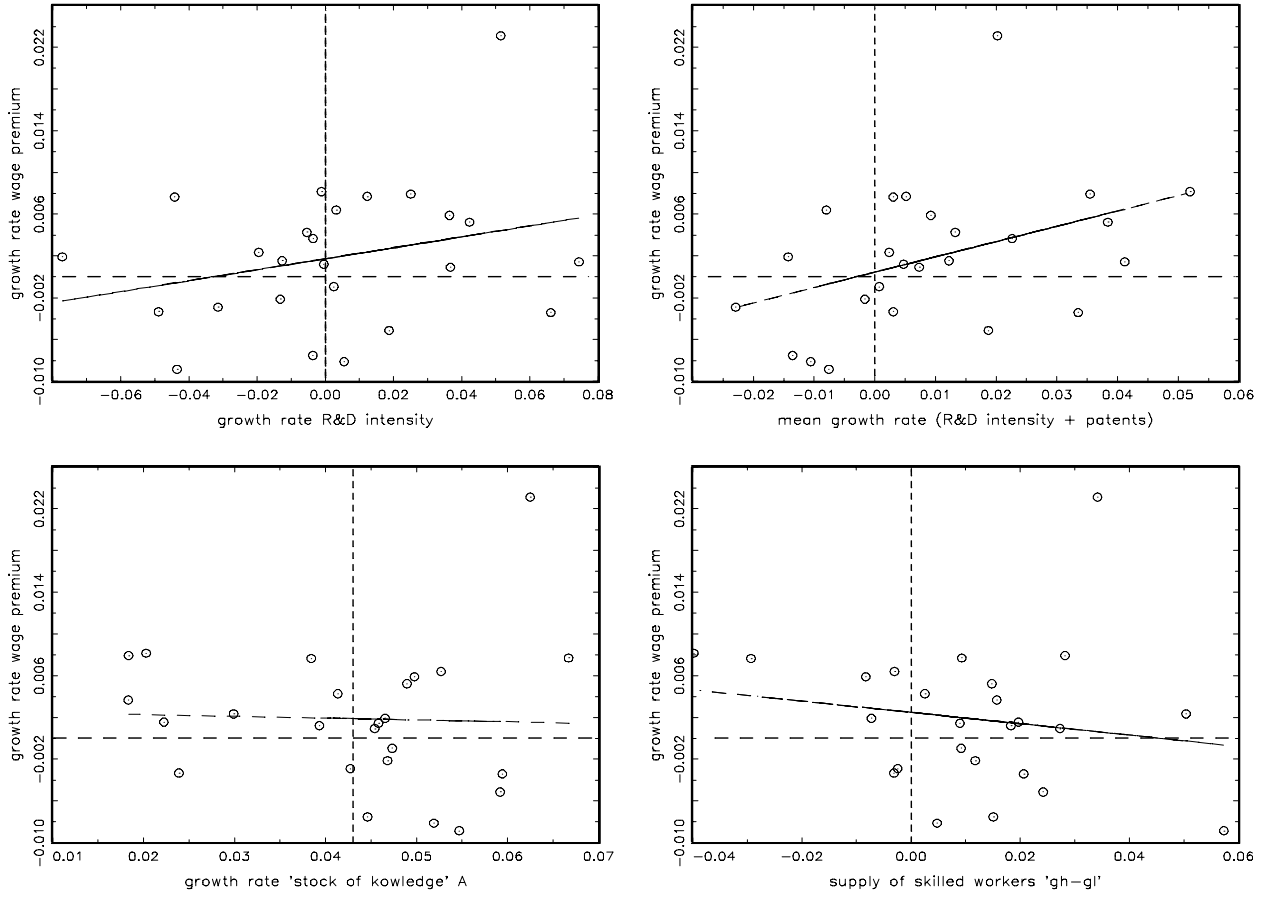


Figure 6: Correlation Germany - Wage Premium (1974-98),

Appendix B: Application of the perpetual inventory method

The perpetual inventory method:

$$A_t = (1 - \delta_A)A_{t-1} + R_{t-1}$$

where the initial condition follows as:

$$A_0 = \frac{R_0}{g + \delta_A}.$$

Note that δ_A denotes the depreciation of knowledge and g is treated as the mean growth rate of R&D expenditures in the whole period. Table 7 shows the parameter values and time period used for calculating the A :

Table 7: Parameter Values

Country	δ_A	g	Time Period
U.S.	0.08	0.028	1960 – 1998
Germany	0.08	0.050	1963 – 1998
Coe / Helpman (1995)	0.05 / 0.15	0.050	1963 – 1990 (Germany)
	0.05 / 0.15	0.025	1963 – 1990 (U.S.)
Gong et. al. (2000)	0.08		1962 - 1996 (U.S.)
	0.08		1962 - 1991 (Germany)

Note that the last four rows show the values of the referred articles.

Appendix C: Data Computations

1. U.S. Data:

For the U.S., the number of higher educated workers consist of the sum of male and female employees which earned some college degree (bachelor’s degree and higher). Low educated employees consist of the sum of employees which earned a high school degree or less. In particular, the U.S. Bureau of the Census distinguishes between less than the 9th degree, the 9th to 10th degree and the high school degree.

Calculating the wage premia, the wage of high skilled labor is approximated by the median of wages of male and female employees with college education. The wage of low skilled labor is given by the median of wages earned by low educated male and female employees.

In the U.S. case we distinguish between so-called college- and wage - premia:

$$\begin{aligned}\text{Wage Premium:} &= \frac{\text{Median wages college education}}{\text{median wages Non- College education}} \\ \text{College Premium:} &= \frac{\text{Median wages college education}}{\text{median wages High- School education}}\end{aligned}$$

Main data source: U.S. Bureau of the Census (1998, 2000).

2. German Data:

In contrast to the U.S., for Germany we employ data for the manufacturing sector, only. The available data are for both male and female blue and white collar workers at different job positions. Because of the German education system we assume blue and white collar workers at supervisory job positions as high skilled labor. In particular, such workers are educated at school for at least 12 years, furthermore they normally got a practical education (apprenticeship). In this line, we assume employees at lower job positions and, therefore, at a lower educational level as low skilled labor. The numbers of employees and the wages for the German economy are calculated as for the U.S.

$$\text{Wage Premium:} = \frac{\text{Median wages at supervisory job positions}}{\text{Median wages at lower job positions}}$$

Main data source: Federal Office of Statistics, Germany, 'Fachserie 16', various issues since 1978.

Appendix D: Data Sources

- OECD, *Employment Outlook*, Paris, 1993, 1996.
- OECD, *Main Science and Technological Indicators*, Paris, various issues since 1988.
- U.S. Bureau of the Census, *Annual Statistical Abstract of the United States*, various issues since 1965.

- U.S. Bureau of the Census (1998), *Measuring 50 Years of Economic Change Using the March Current Population Survey*, Current Population Reports P60-203, Washington DC, September 1998.
- U.S. Bureau of the Census (2000), Current Population Reports P60-209, *Money Income in the United States: 1999*, U.S. Government Printing Office, Washington D.C.
- National Science Foundation (NSF), *Science & Engineering Indicators* 1996, 1998, 2000, Internet source <http://www.nsf.gov/>.
- National Science Foundation (NSF), *National Patterns of R&D - Resources*, 1998, Internet source : <http://www.nsf.gov/>.
- Federal Statistical Office Germany, *Statistisches Jahrbuch der Bundesrepublik Deutschland*, Metzler-Poeschel, Wiesbaden 1990-1998.
- Federal Statistical Office Germany, *Fachserie 1, Bevölkerung und Erwerbstätigkeit, Reihe 4.2.1, Struktur der Arbeitnehmer*, Metzler - Poeschel, Wiesbaden, various issues since 1978.
- Federal Statistical Office Germany, *Fachserie 16, Löhne und Gehälter, Reihe 2.2 und 2.1*, Metzler - Poeschel, Wiesbaden, various issues since 1978.
- Ministry of Education, Science and Technology (BMBF) , *Bundesbericht Forschung 1996*, Bonn, CD-ROM, August 1996.
- Ministry of Education, Science and Technology (BMBF), *Grund- und Strukturdaten 1999/2000*, Bonn.
- German Patent Office, *Blatt für Patent-, Muster- und Zeichenwesen*, Munich, various issues since 1960.

References

- [1] **Acemoglu, D., (1998)**, “Why Do New Technologies Complement Skills? Directed Technical Change and Wage Inequality.” *Quarterly Journal of Economics*, 113: 1055 – 1090.
- [2] **Acemoglu, D., (2002a)**, “Technical Change, Inequality and the Labor Market.” *Journal of Economic Literature*, 40: 7 - 72.
- [3] **Acemoglu, D., (2002b)**, “Cross Country Inequality Trends.” NBER Working Paper No.8832, Cambridge, Mass., March.
- [4] **Aghion, P., Howitt, P., (1998)**, *Endogenous Growth Theory*, 1st. ed., MIT – Press.
- [5] **Aghion, P., Caroli, E., García-Peñalosa, C., (1999)**, “Inequality and Economic Growth: The Perspective of the New Growth Theories.” *Journal of Economic Literature*, Vol. 37, Dec. 1999,: 1615 – 1660.
- [6] **Aghion, P. (2002)**, “Schumpeterian Growth Theory and the Dynamics of Income Inequality.” *Econometrica*, 70(2): 855–882.
- [7] **Berman, E., Bound, J., Machin, S. (1998)** “Implications of Skill-Biased Technological Change: International Evidence.” *Quarterly Journal of Economics*, 113: 1245–1279.
- [8] **Coe, D.T., Helpman, E., (1995)**, “International R&D Spillovers.” *European Economic Review*, 39: 859 - 887.
- [9] **Davis, S. (1992)**, “Cross - Country Patters of Changes in Relative Wages.” In Blanchard, O.J. and Fischer, S. (eds.), *NBER Macroeconomics Annual 1992*: 239–292.
- [10] **Eicher, T.S., García-Peñalosa, C. (2001)**, “Inequality and Growth: The Dual Role of Human Capital in Development.” *Journal of Development Economics*, 66: 173–197.
- [11] **Galor, O., Tsiddon, D. (1997)**, “Technological Progress, Mobility and Economic Growth.” *American Economic Review*, 87(3): 363–382.

- [12] **Galor, O., Moav, O. (2000)**, “Ability-Biased Technological Transition, Wage Inequality, and Economic Growth.” *Quarterly Journal of Economics*, 115: 469–497.
- [13] **Goldin, C., Katz, L.F. (1998)**, “The Origins of Technology - Skill Complementarity.” *Quarterly Journal of Economics*, 113: 693-732.
- [14] **Gong, G., Greiner, A., Semmler, W., Rubart, J., (2001)**, “Economic Growth in the U.S. and Europe: The Role of Knowledge, Human Capital and Inventions.” In Jürgen Gabriel, Michael Neugart (eds.), *Ökonomie als Grundlage politischer Entscheidungen: Essays on Growth, Labor Markets and European Integration*, Leske+Budrich, Leverkusen.
- [15] **Greiner, A., Semmler, W., (2000)**, “Endogenous Growth, Skill-Biased Technical Change and Wage Inequality.” CEM - Working Paper, No. 8, Bielefeld University, February 2001,
Internet Source: <http://www.wiwi.uni-bielefeld.de/~semmler/cem>.
- [16] **Greiner, A., Semmler, W., Gong, G., (2003)**, Economic Growth: A Time Series Perspective, Book Manuscript, Bielefeld University, January.
- [17] **Haskel, J., Slaughter, M.J. (2001)**, “Trade, Technology and U.K. Wage Inequality.” *The Economic Journal*, 111: 163–187.
- [18] **Jones, C., (1995)** “R&D-Based Models of Economic Growth.” *Journal of Political Economy*, Vol. 103: 759-784
- [19] **Katz, L.F., Murphy, K.M., (1992)**, “Changes in Relative Wages, 1963-1987: Supply and Demand Factors.” *Quarterly Journal of Economics*, 107, Feb. 1992: 35 – 78.
- [20] **Katz, L.F., Autor, D.H., (1999)**, “Changes in the wage structure and earnings inequality.” In Ashenfelter, O., Card, D., (eds.) *Handbook of labor economics – Volume III*, Elsevier: 1463 – 1555.
- [21] **Krueger, A.B., Pischke, J.S., (1997)**, “Observations and Conjectures on the U.S. Employment Miracle.” NBER Working Paper No. 6146, Cambridge MA., August 1997.

- [22] **Krugman, P., (1994)**, “Past and Prospective Causes of High Unemployment.” Federal Reserve Bank of Kansas City Economic Review, Fourth Quarter 1994: 23 – 43.
- [23] **Krusell, P., Ohanian, L.E., Ríos-Rull, V., Violante, G., (2000)**, “Capital Skill Complementary and Inequality: A Macroeconomic Analysis.” *Econometrica*, Vol. 68(5): 1029-1053.
- [24] **Machin, S., Van Reenen, J. (1998)** “Technology and Changes in Skill Structure: Evidence from seven OECD Countries.” *Quarterly Journal of Economics*, 113: 1215–1244.
- [25] **Nickell, S., Nunziata, L., Ochel, W., Quintini, G. (2001)**, “The Beveridge Curve, Unemployment and Wages in the OECD from 1960’s to the 1990’s.” Working Paper, Center for Economic Performance, London School of Economics, July.
- [26] **Murphy, K.M., Riddell, W.C., Romer, P.M., (1998)**, “Wages, Skills and Technology in the United States and Canada.” In Helpman, E., (ed.), *General Purpose Technologies and Economic Growth*, MIT Press: 283 – 309.
- [27] **Nickell, S., (1997)** “Unemployment and Labor Market Rigidities - Europe versus North America.” *Journal of Economic Perspectives*, 3: 55-74
- [28] **OECD (1996)**, “The Knowledge Based Economy.” OECD Paris.
- [29] **Romer, P.M., (1990)**, “Endogenous Technological Change.” *Journal of Political Economy*, 98(5),: 71 - 102.
- [30] **Scholl, A. and W. Semmler, (2000)**, “Sustainable Economic Growth and Exhaustible Resources: A Model and Estimation for the U.S.” CEM - Working Paper, No. 1, University of Bielefeld, August 2000.
- [31] **Siegel, D.S., (1999)**, “Skill - Biased Technological Change.” Upjohn Institute for Employment Research, Kalamazoo, Michigan.