Center for Empirical Macroeconomics

The Rate of Technological Change and the Pattern of Wage Inequality

Jens Rubart

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

33501 Bielefeld, Germany

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Abstract

Today, the sources of the different patterns of educational wage differentials across main OECD-member countries are not understood completely. Although the forces driving wage inequality are widely accepted we know little about the impact of each source. In order to shed some light onto the impact of the rate of technological change on educational wage inequality this paper assumes an innovation-based growth model which allows for different educational levels in the output production. Furthermore, estimations with time series data for the U.S. and German economies are employed in order to estimate the important parameters determining the wage differential of the assumed model. The paper concludes that the rate of technological change and a high elasticity of substitution between high an low skilled workers determine U.S. wage inequality. For Germany one has to conclude that other forces like labor market rigidities determine the wage differential.

Key Words: Wage inequality, Technological Change

JEL - Classification: J0, O3.

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University of Bielefeld, Department of Economics and **Center for Empirical Macroeconomics, P.O. Box 100 131, D-33501 Bielefeld, Germany, e-mail: jrubart@wiwi.uni-bielefeld.de

1 Introduction

Comparing the labor markets of various OECD-member countries increasing inequality is observed. The structure of inequality can be decomposed into three main elements: educational wage differentials (called college or wage premium); age related wage differentials and inequality within groups of the same educational level (within group inequality). Although numerous studies about inequality exist the sources of inequality are not completely understood.

In order to shed some light onto the driving forces of inequality this work concentrates, in particular, on educationally related wage differentials. In general educational wage inequality can be treated as an indicator of an excess demand for high skilled people relative to less skilled ones. Beside the 'supply and demand' scheme one has to ask which forces drive the demand for skilled people which ends up in increasing wage inequality. Numerous attempts are, for example, published by Katz and Murphy (1992), Krugman (1994), Murphy et al. (1998), Katz and Autor (1999), Acemoglu (1998, 2000) or Aghion et al. (1999). 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 specific differences between countries. Therefore, the attempt of this study lies in the comparison of U.S. and European economies in order to give an answer why U.S. or U.K. inequality has risen while German or French inequality has not. Basing on an innovation - based growth model, which allows for different skill levels in the output production, wage inequality is determined by the stock of technological knowledge and the supply of skilled workers. From this point of view, the wage premium depends crucially on the conditions of economic growth of an economy.

In general, the main forces driving economic growth are known and widely accepted. Recent work on endogenous growth models shows how innovations, the creation of new knowledge, human- and public capital influences the growth rate of per capita income.[1] In particular, the new growth models assume different educational levels of the labor force. For example, Romer (1990) assumes high skilled workers which are either employed in the research or in the production sector. Otherwise, low skilled workers are only employed in the final goods sector. Concentrating on the production sector the basic

[1]See e.g. Aghion and Howitt (1998) or Gong et al. (2001) for a comparison of U.S. and European growth differences.

ingredients for analyzing educational wage differentials are given: high and low skilled workers.

Considering the world wide labor markets we observe that the number of high skilled people (e.g. an increasing number of college graduates) increases. Applying a simple 'supply and demand' scheme one concludes that their wages should be decline. However, for some countries this effect is not observed. An explanation of these observations is given by the concept of the so-called skill-biased technological change. This argumentation is based on the assumption that technology is complementary to skills. I.e. if technology grows the demand for skilled people increases or an increase in the supply of skills induces faster technology growth which leads to an increasing demand of such people, respectively. An indicator of skill-biased technological change and the demand for skilled people is the wage- or college premium. I.e. the fraction of high skilled wages relative to wages for workers at a lower skill level. Acemoglu (1998) argues that a shift in the supply of skilled people decreases the wage premium *(substitution effect)* in the short run. Induced technological growth shifts the demand curve to the right and leads to an increased wage premium *(technology effect)*.[2] Figure 1 outlines his argumentation. Starting at the initial point A the substitution effect decreases the wage premium to point B. Point C shows the long run wage premium given by the shift of the demand curve driven by the technology effect.

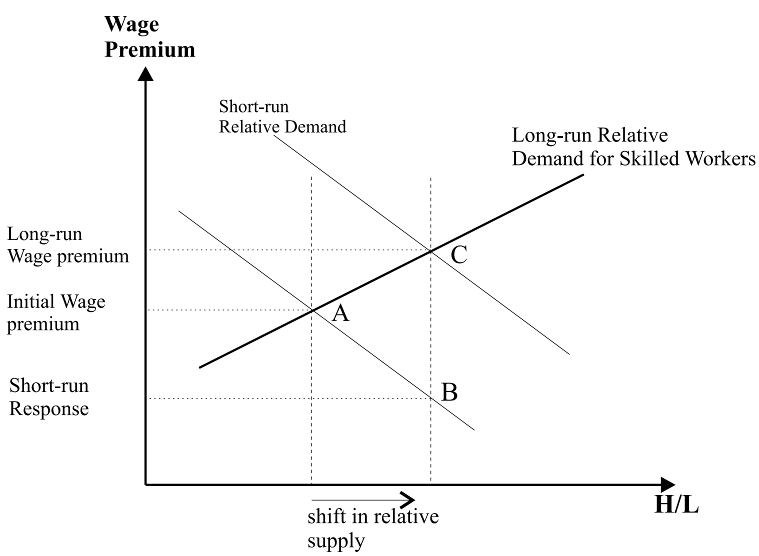

Figure 1: Supply of skilled workers and the Wage Premium

[2]See Acemoglu (1998), page 1057.

The structure of the model presented by Acemoglu (1998) was already examined empirically by Katz and Murphy (1992) who estimated parameter values for the U.S. close to the prediction of Acemoglu's model. However in Europe, especially in Germany, we observe different patterns of wage premia. For example, for West-Germany the wage premium decreases. One of the main results of this work is that the substitution between skilled and unskilled workers behaves extremely different in the U.S. and Germany. This result might indicate that the demand curve for (high) skilled workers behaves differently than in the U.S.

The remainder of this paper is organized as follows. Section two presents some stylized facts about wage inequality and the supply of skilled workers of main OECD-member countries. Section three develops the determinants of the wage premium based upon an innovation-based growth model. Section four presents estimation results for the U.S. and German economies. Section five concludes.

2 Some Stylized Facts

Before deriving a theoretical model of wage inequality one should consider some stylized facts about inequality. Figure 2 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. The data of wage differentials are taken from the OECD Employment Outlook (1993, 1996) and show the ratios of the 10th (D1) and 50th (D5) - percentiles to the 90th (D9) percentile wage earners.[3] It can be shown, e.g. by the German GSOEP - data, that the median income of different educational groups increases with the level of education. Therefore, the 90th - percentile of the income distribution shows the wages earned by high skilled people. The opposite case is observed for the 10th percentile. There, the wage earners got a low education. Furthermore, long time series for U.S. wage data are taken from the U.S. Bureau of the Census (1998). For Germany a separate time series of wage inequality is constructed by using German Socioeconomic Panel (GSOEP) data.

Considering figure 2 one observes that the D9/D5 - ratios increase moderately or remain constant for each country. Furthermore, the D9/D1 - ra-

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

tios, constructed by OECD data, increase sharply for the U.S. and the United Kingdom. For Germany one observes a decreasing patters while for France the D9/D1-ratio remains roughly constant.

Concentrating on the GSOEP - Data we observe that each ratio remains at a constant level[4]. For the U.S. 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.

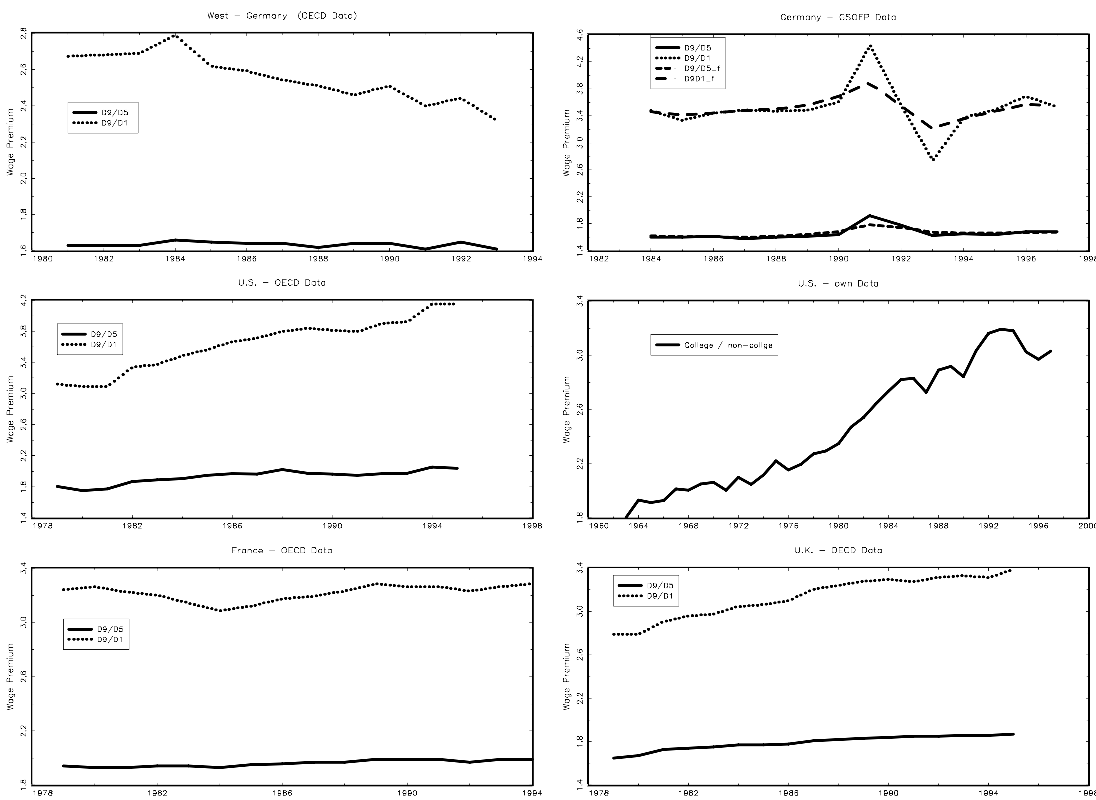

Figure 2: Patterns of Wage Premia

Source: OECD (1993, 1996), GSOEP (1999), U.S. Bureau of the Census (1998).

Figures 3 and 4 show an increasing employment of high skilled people.

[4]The dashed time series are smoothed by using the Kalman Filter and the break between 1990 and 1993 is explained by changes in the sample size (East-Germany is included since 1993). Furthermore, the U.S. time series from 1963-97 and the German GSOEP time series are own calculations.

Figure 3 present the ratio of college educated workers (bachelor's degree and higher) in per cent of total employees. Figure 4 shows the ratio of university educated employees on total employees for Germany. Both figures show positive time trends for the U.S. and Germany.

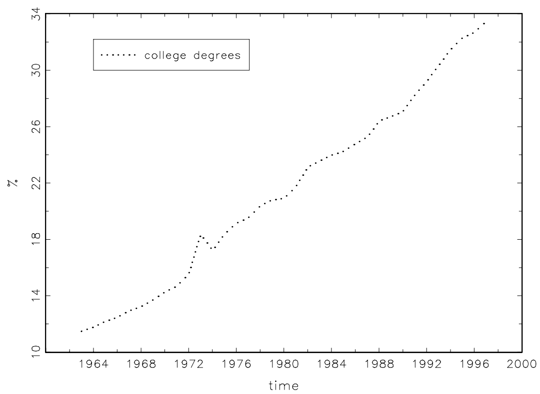

Figure 3: High Skilled Employment, U.S. 1963-1997.

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

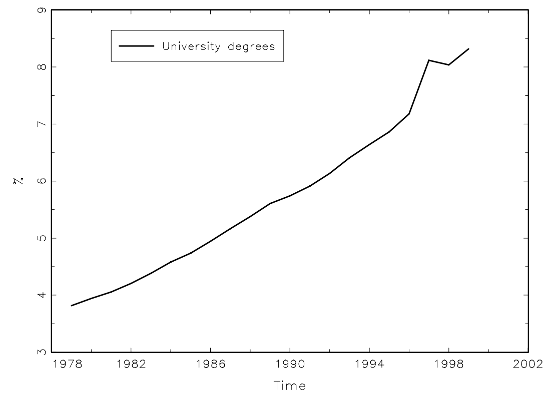

Figure 4: High Skilled Employment, Germany 1979-1999.

Source: Federal Office of Statistics and own calculations

Taking into account that the number of students (measured in % of employees) remains constant one might argue that there should be an excess demand for high skilled people in both countries. An argument which seems to hold in the U.S. case because of the increasing wage premium. For Germany this argument does not seem to hold because of the declining wage premium.

In the line of Acemoglu (2000) one might interpret figures 2, 3 and 4 that there is a shift in the demand curve for skilled people (skill-biased technological change) in the U.S. Furthermore, the German economy seem to be affected by substitution effects that shift the wage premium downwards. The following model attempts to explain the above stylized facts in the context of an innovation-based growth model.

3 The Model

The idea of the model presented in this section bases on the market version of the Romer (1990) endogenous growth model. Furthermore, the work of Murphy et al. (1998) and Greiner and Semmler (2001) is used to model its implications for the evolution of the wage premium. In particular, the wage premium is derived by a modified production function of the final goods sector which includes different levels of skilled workers. The production function is given by

$$Y = K^{1-\alpha} A^{\alpha} \eta^{\alpha-1} \Big\{ \gamma \big[A^{\xi} (H - H_A) \big]^{\frac{\sigma-1}{\sigma}} + (1-\gamma) \big[A^{\epsilon} L \big]^{\frac{\sigma-1}{\sigma}} \Big\}^{\frac{\alpha\sigma}{\sigma-1}}, \qquad (1)$$

where K denotes the stock of physical capital, H is the number of high qualified employees, L gives the number of low qualified workers and A denotes the stock of technological knowledge. Note that the stock of human capital is divided into skilled people employed in the output production H_Y and employed in the research sector H_A. Therefore, the total number of high qualified employees is given by $H = H_A + H_Y$. The elasticity of substitution between H_Y and L is given by $\sigma > 1$. The parameters ξ and ϵ measure the impact of the external effect on H_Y and L raised by technological developments. $\gamma \in (0, 1)$ denotes a productivity parameter of skilled and unskilled workers. Last, η measures the units of foregone output which are needed to produce one unit of an intermediate good. However, without loss of generality, it is assumed that $\eta = 1$. Now, equation (1) reduces to:

$$Y = K^{1-\alpha} A^{\alpha} \Big\{ X \Big\}^{\frac{\alpha\sigma}{\sigma-1}}, \qquad (2)$$

where

$$X = \gamma \big[A^{\xi} (H - H_A) \big]^{\frac{\sigma-1}{\sigma}} + (1-\gamma) \big[A^{\epsilon} L \big]^{\frac{\sigma-1}{\sigma}}.$$

The economy is assumed to consist of three sectors: a R&D Sector which produces new knowledge and an intermediate goods sector which produces new capital goods x. The final goods sector uses intermediate goods, skilled and unskilled workers in order to produce a final good which can either be consumed or invested. Furthermore, the household is assumed to consist of a representative agent which maximizes its intertemporal utility subject to a budget constraint. Table 1 shows a brief outline of the production sectors and equations explaining the assumed economy.

Table 1: 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 designs	produces x buys a design (fixed cost)	$Y = K^{1-\alpha} A^{\alpha} \Big\{ X \Big\}^{\frac{\alpha\sigma}{\sigma-1}}$
competitive	monopolistic	competitive

The complete derivations of the market equilibrium and conditions for long run economic growth are given in Greiner and Semmler (2001). Because they are not necessary for the determination of the wage premium they are neglected in this work.

The wage or college - premium is defined as the ratio of wages earned by skilled workers and the wages earned by low skilled workers. Furthermore, it is assumed that each worker is paid by its marginal product[5]. It follows from (2)

$$\begin{aligned} w_H &= \alpha\gamma K^{1-\alpha} A^{\alpha} X^{\frac{\alpha\sigma}{\sigma-1}-1} A^{\frac{\xi(\sigma-1)}{\sigma}} H_Y^{-\frac{1}{\sigma}} \qquad (3) \\ w_L &= \alpha(1-\gamma) K^{1-\alpha} A^{\alpha} X^{\frac{\alpha\sigma}{\sigma-1}-1} A^{\frac{\epsilon(\sigma-1)}{\sigma}} L^{-\frac{1}{\sigma}}. \qquad (4) \end{aligned}$$

Dividing (3) by (4) the wage premium follows as

$$w_p \equiv \frac{w_H}{w_L} = \frac{\gamma}{1-\gamma} \Big[A^{\xi-\epsilon} \Big]^{\frac{\sigma-1}{\sigma}} \Big[\frac{H_Y}{L} \Big]^{-\frac{1}{\sigma}} \qquad (5)$$

Comparing equation (5) with the result of Murphy et al. (1998) one obtains a very similar equation[6].

$$\tilde{w_p} = c \Big[\frac{A(t)}{B(t)} \Big]^{\frac{\sigma-1}{\sigma}} \Big[\frac{H}{L} \Big]^{-\frac{1}{\sigma}}, \qquad (6)$$

where c denotes a positive constant, σ is the elasticity of substitution, $A(t)$ and $B(t)$ are levels of technological knowledge available to high and low skilled workers. The differences between equations (5) and (6) are that in the model

[5] Referring to Romer (1990) a necessary condition for the long run equilibrium is that the wages for high skilled workers in the R&D or the production sector are equal. The same condition has to be fulfilled for the low skilled wages in the production or intermediate sector. Therefore it is sufficient to concentrate on the results of equation (2).

[6] See Murphy et al. (1998), page 294.

of Greiner and Semmler (2001) there exists only one stock of technological knowledge which is available to any worker. Furthermore, equation (5) assumes an external effect of technical change $(\xi - \epsilon)$.

Returning to equation (5) taking logs and differentiating with respect to time we obtain the growth rate of the wage premium:

$$\hat{w}_p = \frac{\dot{w}_p}{w_p} = \Big(\frac{\sigma - 1}{\sigma}\Big)(\xi - \epsilon)g_A - \frac{1}{\sigma}\Big(g_H - g_L\Big), \tag{7}$$

where $g_A = \frac{\dot{A}}{A}$, $g_H = \frac{\dot{H}_Y}{H_Y}$ and $g_L = \frac{\dot{L}}{L}$.
Now, one can identify two influences determining the wage premium:[7]

1. The technology effect:
   The technology effect is driven by the sign of $(\xi - \epsilon)$. If $\xi > \epsilon$ leads to a higher productivity of high skilled workers. I.e. this leads to a higher demand for skilled workers which increases the wage differential.

2. 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. I.e. if σ is high $(\sigma > 1)$ skilled workers cannot be substituted by low skilled workers, easily. In this case, an increasing number of high skilled people has only a small negative effect on the wage premium. If σ is low $(\sigma < 1)$ the opposite holds.

Referring to equations (5) and (7) the 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. The following section presents time series data and estimations for two OECD - member countries, Germany and the U.S.

4 Data and Estimation

4.1 Data Sources and Computations

Considering equation (7) we need data for H_Y, L and A. H_Y is represented by employed civilian workers which earned a college degree (bachelor's degree

[7]Mention that the level of the wage differential (see equation (5)) also depends on the growth rates of A, H_Y and L and on the productivity parameter γ.

and higher). L denotes the number of employees with a degree less than a bachelor's degree. For the U.S. the data are taken from the Annual Statistical Abstract (various issues since 1975) and the U.S. Bureau of the Census (1997). 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 (1997), OECD (1993, 1996) and the German Socio - Economic Panel (GSOEP) published by the German Institute for Economic Research (DIW) in 1999. For Germany the time series taken from the OECD include West - German data only. The time series constructed by the GSOEP data include the reunified Germany since 1993.

A primary problem was to construct a reliable measure of the stock of knowledge A. In particular, various measures of a stock of knowledge exist[8]. A measure of a stock of knowledge should include innovative investments, a measurable output of knowledge production and the flow of informations about knowledge. An approximation of the first two items are possible through research and development (R&D) - investments 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 3 (see table 1) 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, the growth rate of the stock of knowledge will be considered as the mean growth rates of real R&D - Expenditures and the number of national patent grants. The advantage of the measure applied in this work is that comparable long-run time series data are available for the U.S. and German economies. The U.S. data are taken from National Science Foundation (2000), for Germany from the Federal Statistical Office and from the German Patent Office. The following table summarizes the computation of the employed time series data:

[8]See e.g. Gong et al. (2001) or OECD (1996b).

Table 2: Data Computations

Variable	Data
$\hat{w}_p$	Time Series of Wage Differentials
g_A	mean growth rate of R&D-Exp. + Patents
g_H	Employees with College education
g_L	Employees without college education

4.2 Outliers and Data Correction

Considering the collected time series data (see e.g. the German GSOEP - Data (figure 2)) one has to deal with breaks and large and unrealistic outliers. In order to deal with the observed errors, see e.g. table 3 a fixed interval - smoothing algorithm of the Kalman Filter is applied in order to correct the time series.[9] The applied smoothing algorithm bases on a univariate, time-variant state space model of a time series

$$y_t = \alpha_t + \phi_t \quad (8)$$

$$\alpha_t = \alpha_{t-1} + \varphi_t. \quad (9)$$

There, equation (8) is called a measurement equation and equation (9) is called a state equation.[10] The specification above allows the state vector α to match fundamental structures of a given time series. Following Koopman (1998) smoothing a time series by the Kalman Filter is interpreted as an estimation of the true mean of a time series. In particular, applying Kalman filtering and smoothing to data including obvious measurement errors the local level model opens the possibility to extract information about the 'true' value of a specific time series.[11]

[9] See Appendix A for a brief sketch of the Kalman Filter and the applied smoothing algorithm.

[10] This particular form of a state space model is also called the 'local level model'.

[11] See Koopman (1998), page 2146.

For example, applying the Kalman Filter to the German GSOEP - Data produces the following results:

Table 3: Kalman Filter Results

	$\frac{D9}{D5}$		$\frac{D9}{D1}$	
	original	smoothed	original	smoothed
min	-0.0891	0.0136	-0.3567	-0.0241
max	0.1617	0.0342	0.2096	0.0301
st. dev.	0.0593	0.0136	0.1670	0.0171

In particular, the original $\frac{D9}{D1}$ - series show annual growth rates in a range from -35.67 to $+20.96$ % per year. Such values seem extremely impossible, in particular, for the German Economy. Applying the Kalman Filter transforms the interval to a range between -2.41 and 3.01 % per cent. Furthermore, the standard deviation (st. dev.) of each time series is reduced, too.

Figure 5 presents the original and the 'smoothed' growth rates of the U.S. wage premium.

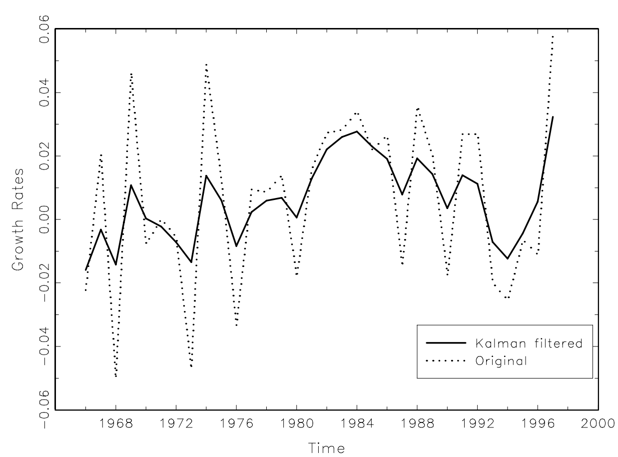

Figure 5: Result of the Kalman Filter

For the U.S. time series we observe similar results. High outliers are corrected but the underlying trend is matched. Generally, for both time series it is observed that the Kalman Filter produces a new time series which matches most of the underlying structure of the original series.

4.3 Estimation Results

Before estimating the coefficients of equation (7), correlation coefficients between wage inequality and the applied measures of technological knowledge and human capital are analyzed. Tables 4 and 5 present the achieved results for the U.S. and German Economies.

Table 4: Correlation, U.S.

		Patents	tot. R&D	g_A	g_{HL}
1966-97	$\frac{\text{wage college education}}{\text{wage non-college educ.}}$	0.3679	-0.0357	0.2965	-0.3350
1980-95	OECD $\frac{D9}{D5}$	-0.2251	0.5057	0.1507	0.1513
1980-95	OECD $\frac{D9}{D1}$	-0.2050	0.5302	0.1969	0.0814

Table 5: Correlation, Germany

		Patents	tot. R&D	g_A	g_{HL}
1985-97	GSOEP $\frac{D9}{D5}$	0.0384	-0.7832	0.4767	-0.0077
1985-97	GSOEP $\frac{D9}{D1}$	0.3764	-0.1818	0.2204	0.0219
1982-95	OECD $\frac{D9}{D5}$	-0.2826	-0.6202	0.0385	-0.4560
1982-95	OECD $\frac{D9}{D1}$	-0.3461	0.0227	-0.2644	-0.4897

Considering the results of table 4 and table 5 we observe that g_A correlates positively with the wage premium in the U.S. and Germany (in Germany except for the OECD $\frac{D9}{D1}$ - Data). This fact indicates that in both countries an increasing level of technological knowledge raises the wage premium (e.g. through demand effects). Furthermore, we observe for the 1966-97 time series of the U.S. that the relative supply of skilled decreases the wage inequality. Otherwise, we observe for the U.S. a positive correlation between the relative supply of skills and the employed OECD - data. This might be random or even another indicator of skill-biased technical change. For Germany the opposite case is observed. There, the relative supply of skilled workers is only little or negatively correlated with the wage inequality. Interpreting the results in terms of figure 1 one has to conclude that in Germany there seem to be no demand effects that influence the wage premium. However, the opposite conclusion may hold for the U.S. economy.

The following step estimates the wage premium, given by equation (7), directely. Because of the structure of equation (7) it seems sufficient to apply Ordinary Least Squares (OLS) estimation. To be consistent with the equation (7) and the work of Katz and Murphy (1992) and Murphy et al. (1998) the following equations are estimated

$$\hat{w}_p = \beta_1 g_A + \beta_2 g_{HL} + \varepsilon \quad (10)$$

$$\hat{w}_p = \beta_0 + \beta_1 g_A + \beta_2 g_{HL} + \varepsilon \quad (11)$$

where $g_A = \frac{\dot{A}}{A}$ and $g_{HL} = (g_{H_Y} - g_L)$.
Table 6 presents the results for the U.S.[12]

Table 6: OLS – Estimation, U.S.

		Equation (10)		Equation (11)		
		β_1	β_2	β_0	β_1	β_2
1966-97	$\frac{\text{wage college education}}{\text{wage non-college educ.}}$	1.1140***	-0.1263	0.0214***	0.3159*	−0.2773*
		(0.1162)	(0.1968)	(0.0078)	(0.1586)	(0.2325)
1966-80	$\frac{\text{wage college education}}{\text{wage non-college educ.}}$	0.9669***	-0.2257	0.0178*	0.2748	-0.3655
		(0.1868)	(0.3234)	(0.0111)	(0.4681)	(0.3179)
1980-97	$\frac{\text{wage college education}}{\text{wage non-college educ.}}$	1.1790***	-0.0522	0.0256**	0.2870*	−0.2881**
		(0.1427)	(0.2318)	(0.0054)	(0.2082)	(0.1585)
1980-95	OECD $\frac{D9}{D5}$	0.1111	0.3505	-0.0015	0.1326	0.4106
		(0.1106)	(0.4446)	(0.0101)	(0.2007)	(0.6064)
1980-95	OECD $\frac{D9}{D1}$	0.3107*	0.6256	0.0088	0.1666	0.2812
		(0.1178)	(0.4735)	(0.0105)	(0.2083)	(0.6295)

Significance levels: ()*** = 95% ; ()** = 90% ; ()* = 80%

It should be expected that $\beta_0 = 0$, because otherwise the wage premium has always a certain time trend (i.e the growth rate is never zero). The results for equation (11) show significant results for β_0. Therefore, one should take the results of equation (11) with care. One of the most interesting results of equation (11) is that β_1 is always positive and β_2 is negative. In particular, one might interpret the results for β_1 (equation 10) the U.S. wage inequality is, especially, driven by technological progress. Returning to equation (11) and comparing the results of the time period from 1966-80 with the results of the

[12]Standard Errors in parentheses.

second time period we observe that β_1 and β_2 change from insignificant parameter values to significant ones. This effect might be interpreted as an increasing influence of technological progress on the labor market, in particular, on the demand for certain groups of employees. A second outcome of the estimated parameter values of equation (11) is that the external effect of technology[13] is always positive (around 0.40) and the elasticity of substitution lies in an interval between 2.74 and 3.61.[14] The results of equation (10) indicate always significant values for β_1 but no significant results of β_2. Except in the last row of table 6 no OECD - data produce significant results.

Table 7: OLS – Estimation, Germany

			Equation (10)		Equation (11)		
			β_1	β_2	β_0	β_1	β_2
1980-95	GSOEP	$\frac{D9}{D5}$	0.3319	-0.4052	-0.0121	0.6388*	0.3046
			(0.2043)	(0.9477)	(0.0120)	(0.3672)	(1.1813)
1980-95	GSOEP	$\frac{D9}{D1}$	0.2431	0.0042	-0.0053	0.3774	0.3147
			(0.2726)	(1.2644)	(0.0167)	(0.5116)	(1.6456)
1982-93	OECD	$\frac{D9}{D5}$	0.0461	-0.0514	0.0255*	-0.0786	-0.6005^*
			(0.1393)	(0.0709)	(0.0168)	(0.1545)	(0.3673)
1982-93	OECD	$\frac{D9}{D1}$	-0.2377	-0.1861	-0.0867^{***}	-0.6615^{**}	2.0533***
			(0.3369)	(0.1717)	(0.0351)	(0.3236)	(0.7693)

Significance levels: $()^{***} = 95\%$; $()^{**} = 90\%$; $()^{*} = 80\%$

The achieved results for the German data are almost insignificant. There, only two coefficients are significant at least at the 90 % - level (table (7), 3rd row). The result for β_2 indicates $\sigma > 1$, an indicator for inelastic substitution of high skilled workers by low skilled workers ($\sigma = 1.67$). Although the obtained results for β_0, β_1 and β_2 are highly significant (table 7, last row), the signs of the coefficients seem surprising ($\beta_1 < 0; \beta_2 > 0$). In this case, it follows that $\sigma < 0$ (-0.49) which seems to be unrealistic.[15] Together with the result of ($\beta_2 = -0.6615$) the regressions show that the technology effect $(\xi - \epsilon)$ has to be negative ($\xi < \epsilon$). I.e., that an increase in technology affects the productivity

[13] Note that σ is given by: $\sigma = \frac{1}{-\beta_2}$ and $(\xi - \varepsilon) = \beta_1 \frac{\sigma}{\sigma - 1}$.

[14] Katz and Murphy (1992) assume σ in an interval between 0.5 and 4.

[15] One should mention that a negative elasticity of substitution indicates complementary goods.

of low skilled more than for high skilled workers. However, referring to figure 2 which shows flat patterns of the German wage differentials the achieved results might be spurious. Overall the insignificant results for Germany signals that there might be variables missing that impact wage differentials. For Example, in Germany trade unions were always an important factor in wage setting. In particular, it was a declared policy of trade unions since the 1960's to reduce inequality.

5 Conclusion

Of course, research on wage inequality has to include further influences. Two forces, which are neglected in the first part of this study are within - group inequality and the role of worldwide technology flows through foreign trade.

Within group inequality describes the observation that wages earned by workers with the same qualification are not the same. Aghion et al. (1999) 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 heterogenous which leads to increasing wage differentials within groups of similar educational 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 educational wage inequality. In the long-run the rising wage inequality will lead to a reduction of the ratio of high skilled to unskilled workers. However, Krugman (1994) argues that if international trade 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".*[16]

In particular, two "common factors" driving wage inequality and relative

[16]See Krugman (1994), page 36.

demand for skilled workers are the rate of technological change and the elasticity of substitution between high and low skilled workers.[17] This study has shown two differences in the pattern of U.S. and German wage inequality. First, the inequality in the U.S. increases while the wage differential in Germany remains constant or even decreases. Secondly, we have shown two forces which might lead to an increasing wage inequality: a positive technology effect and a high elasticity of substitution between high and low skilled workers. Regression results for the U.S. economy have shown that the technology effect is positive (skill-biased technological change) and a high elasticity of substitution. The achieved results for Germany almost have shown insignificant results. An interpretation of these results is that other factors influence the wage setting (e.g. labor market rigidities, strong trade unions, etc.) in Germany. For example, it was a declared policy of the trade unions since the 1960's to reduce wage inequality in wage bargaining. This likely seems to be the most important factor explaining most of the insignificant regressions in table 7.

Although only aggregated data are employed in this study main influences on the observed patterns of wage inequality could be worked out for the U.S. and German economies in more detail. The work with a more precise measure of the stock of technological knowledge or with disaggregated / sectoral data is left for future research.

[17]See e.g. Krueger and Pischke (1997) who strengthen the importance of the labor demand in order to explain the low U.S. unemployment rate. They argue that the increase in U.S. employment was driven by shifts of the labor demand curve to the right.

A The Kalman – filter

The Kalman Filter is based on the state space form of a structural time series model. The linear state space form of univariate time series y_t is given by:[18]

$$y_t = \alpha_t + \phi_t \qquad \phi_t \sim NID(0, \sigma^2_\phi) \tag{12}$$

$$\alpha_t = \alpha_{t-1} + \varphi_t \qquad \varphi_t \sim NID(0, \sigma^2_\varphi) \ , \tag{13}$$

where (12) is called a measurement equation and (13) a state equation. Given the state space form of a time series the Kalman Filter produces the optimal estimation of α_t on the basis of data observed until time $t-1$ or t,

$$\hat{\alpha}_t = a_{t|t-1} \equiv E\big(\alpha_t | Y_{t-1}\big) \quad \text{or} \quad \breve{\alpha}_t = a_{t|t} \equiv E\big(\alpha_t | Y_t\big)$$

where $Y_{t-1} \equiv \big(y_{t-1}, ..., y_1\big)'$ and $Y_t \equiv \big(y_t, ..., y_1\big)'$, respectively. It should be mentioned that the estimation of $\hat{\alpha}_{t|t-1}$ is also called 'one-step-Prediction' and the estimation of $\breve{\alpha}$ denotes 'Kalman - Filter'. For the derivation of the Kalman Filter in detail the reader is referred to the existing literature (e.g. Koopman (1998), Hamilton (1994) or Harvey (1989)).

The smoothing algorithm used in this study is a 'fixed - interval' smoothing - algorithm. The advantage of this particular smoothing algorithm is that it leads to an estimation of α_t based on the full set of available data, i.e.

$$\tilde{\alpha}_t = a_{t|T} \equiv E\big(\alpha_t | Y_T\big),$$

where $Y_T \equiv \big(y_1, ..., y_t, ..., y_T\big)'$ and $\tilde{\alpha}_t$ denotes the smoothed estimate of the state in time t.

B 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.

[18] NID = normally independent distributed.

- 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.

- 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.

- 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 Institut for Economic Research, *DIW - SOEP (1999), CD - ROM (1984 – 1998)*, Project Group Socio-Economic Panel, Berlin.

- 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., (2000)**, "Technical Change, Inequality and the Labor Market", NBER Working Paper No. 7800, July 2000.

[3] **Aghion, P., Howitt, P., (1998)**, *Endogenous Growth Theory*, 1st. ed., MIT – Press.

[4] **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.

[5] **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", CEM - Working Paper, No. 7, University of Bielefeld, January 2001,
`Internet Source: http://www.wiwi.uni-bielefeld.de/~semmler/cem.`

[6] **Greiner, A., Semmler, W., (2000)**, "Endogenous Growth, Skill-Biased Technical Change and Wage Inequality", CEM - Working Paper, No. 8, University of Bielefeld, Feb 2001,
`Internet Source: http://www.wiwi.uni-bielefeld.de/~semmler/cem.`

[7] **Hamilton, J.D., (1994)**, *Time Series Analysis*, 1st ed., Princeton University Press, New Jersey.

[8] **Harvey, A. C., (1989)**, *Forecasting structural time series models and the Kalman filter*, 1st ed., Camebridge University Press.

[9] **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.

[10] **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.

[11] **Koopman, S. J., (1998)**, "Kalman Filtering and Smoothing", in *Encyclopedia of Biostatistics*, Armitage, P., Colton, Th., eds., Wiley & Sons, New York, 2145 – 2154.

[12] **Krueger, A.B.., Pischke, J.S., (1997),** "Observations and Conjectures on the U.S. Employment Miracle", Working Paper # 390, Industrial Relations Section, Princeton University.

[13] **Krugman, P., (1994)**, "Past and Prospective Causes of High Unemployment", Federal Reserve Bank of Kansas City Economic Review, Fourth Quarter 1994, 23 – 43.

[14] **Murphy, K.M., Riddel, 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*, 283 – 309, MIT Press.

[15] **OECD (1996b)**, "The Knowledge Based Economy", OECD Paris.

[16] **Romer, P.M., (1990)**, "Endogenous Technological Change", Journal of Political Economy, 98(5), 71 - 102.