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Heterogeneous Labor, Labor Market Frictions and Employment Effects of Technological Change

Theory and Empirical Evidence for the U.S. and Europe

Jens Rubart

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Economic Theory

Heterogeneous Labor, Labor Market Frictions and Employment Effects of Technological Change*

— Theory and Empirical Evidence for the U.S. and Europe —

by

Jens Rubart‡

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Abstract

During the last two decades the so called IT revolution has led to a diverse pattern of growth and employment in OECD countries. In particular, anglo-saxon economies like the U.S. or the U.K. exhibited high rates of economic performance and low unemployment rates, whereas continental European countries showed low economic growth and high unemployment rates.

Based on the findings of Lindquist (2004) that the relative demand for workers of different skills (measured by the variation of educational wage differences) varies significantly over the business cycle, we develop a dynamic general equilibrium model which accounts for skill biased technology shocks as well as for the employment record of labor which is divided into different categories of skills. Furthermore, the labor market is characterized by search and matching frictions which allows us to analyze different kinds of institutional settings which determine the negotiated wage rates as well as the demand for labor of the respective skill group. In particular, the latter assumption enables us to control for stylized facts of continental European labor markets.

By confronting our theoretical results to empirical evidences it is shown that labor market frictions are necessary to reproduce empirical findings as the lagged response of output, wages and employment after unanticipated shocks to technology.

JEL - Classification: E32, J21,J23, J24, J31, J41

Keywords : DGE Model, Heterogenous Labor, Skill Biased Technological Change, Search Unemployment

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‡Institute of Economics, Darmstadt University of Technology, Residenzschloss, D-64283 Darmstadt, Germany and Center for Empirical Macroeconomics, University of Bielefeld, e-mail: rubart@vwl.tu-darmstadt.de.

1 Introduction

During the last decade, main continental European countries are faced with the dilemma of high and increasing unemployment rates and, particularly in the case of Germany, low economic growth. In contrast, anglo-saxon countries, like the U.S. or the U.K. exhibit decreasing unemployment rates and higher rates of economic growth. In particular, the rigidity of continental European labor markets seen as the major source for the increasing unemployment rates.[1]

However, when the unemployment record is considered one is confronted with a so-called two-tier picture concerning the fluctuation and level of unemployment rates of different groups of workers (see e.g. Saint-Paul (1996)). In general, one observes an upper tier with high employment (as well as low employment variation) high wages and high job security and a lower tier with high unemployment which is also characterized by high employment variation. As we will show below[2] this observation holds for the unemployment pattern of high and low skilled workers.[3]

A general explanation of this observation, particularly of the steady increase in the unemployment rate of low skilled workers, is given by Krugman (1994) who states that technological advances increased the labor demand for skilled workers, only, whereas the decline in demand for low skilled workers has led to the steady increase of unemployment of this skill group. In addition, this hypothesis could be extended by the findings of Phelps and Zoega (2001) who point out that the observed path of unemployment is, amongst others, subjected to non-monetary shocks and developments, mainly due to investment activities of firms. Considering the investment per GDP ratio for the U.S., U.K., France and Germany one observes a steady increase of this ratio from 15% to 19.8% (16.3%) for the U.S. (U.K.) whereas the same ratio declined from 28.8% (24.1%) to 18.4 % (20.2%) for Germany (France) between 1970 and 2004. However, the fraction of investment in new technologies, like information and communication technologies exhibit a significant increase between 1980 and 2000, i.e. from 15.2% to 39.9% for the U.S. or from 12.2 to 16.2 % for Germany.[4] Besides the skill mismatch as one source of the decreasing demand for low skilled workers, wage rigidities and a certain degree of labor market inflexibility

[1] See, e.g. Blanchard and Wolfers (2000) or Heckman (2003) for detailed surveys of the impact of labor market institutions on the employment record.

[2] See figures 1 and 2 as well as table 1.

[3] The problem of dualism and different skill groups was already mentioned by Malinvaud (1986).

[4] The data are taken from the OECD Main Economic Indicators 2005 (Investment / GDP ratio) and from Colecchia and Schreyer (2001) (ICT - Investment / Total Investment).

prevented wages to adjust downwards which also led to the observed increase in the unemployment rate of low skilled workers.[5] However, as pointed out by Nickell and Bell (1995, 1996) time phases exist in which both unemployment of high and low skilled workers tend to increase, an observation which is not consistent with skill biased technological change as the only source of the high unemployment rates of low skilled workers. As emphasized by Nickell and Bell (1995) a detailed analysis of the consequences of a shock on the relative employment status is missing, *[...] it is essential to understand the consequences for unemployment relativities of a neutral shock [...]* .[6]

Up to now, the transmission process of technological advances to the employment (unemployment) status of different types of workers remains unclear, particularly when labor market frictions are taken into account. The recent paper attempts to bridge the gap between empirical findings and theoretical explanations of the observed unemployment pattern. We combine the hypothesis of skill biased technological change with the assumption of search and matching frictions on the labor market within a dynamic general equilibrium (DGE) model of the business cycle. This allows for the examination of the 'transmission mechanism' of technological advances as well as it enables us to evaluate the simulation results of the model with observed business cycle evidences.

The hypothesis of skill biased technological change (SBTC) and its labor market implications are widely discussed by Acemoglu (1999), Mortensen and Pissarides (1999) or in the recent paper by Hornstein et al. (2005). However, concentration on the long-run impact of SBTC (as in Acemoglu (1999)) or rather partial equilibrium models as in Mortensen and Pissarides (1999) which are often found in the theoretical approaches seems not sufficient in order to account for the observed unemployment pattern. For example, partial equilibrium models do not account for capital accumulation and possible substitution effects between certain variables as, for example, capital and labor. An explanation of the observed fluctuations of the wage spread and the variability of working hours of different types of workers within a DGE framework is presented by Lindquist (2004). Related lines of research can be found in the work by Ljungqvist and Sargent (1998), Albrecht and Vroman (2002), Gautier (2002) as well as Pierrard and Sneessens (2003). In particular, we extend the work by Gautier (2002) or Pierrard and Sneessens (2003) by introducing capital

[5] A recent study of the skill mismatch in OECD is given by Petrongolo and Manacorda (1999).
[6] Cf. Nickell and Bell (1995): 43.

accumulation, labor - leisure choice of the households as well as skill-augmenting technology shocks. The latter assumption enables us to examine the effects of skill enhancing policies on the employment status of the respective skill group. In contrast to Gautier (2002) and Pierrard and Sneessens (2003) our model assumes (in line with Mortensen and Pissarides (1999)) a segmented labor market where skilled and unskilled workers can only apply for skilled and unskilled jobs, respectively. This assumption simplifies the analysis and is also in line with recent empirical evidences by Gottschalk and Hansen (2003). Our analysis concludes with a comparison of the obtained results with the outcomes a model without labor market frictions.

Furthermore, many empirical evidences are based on time-invariant examinations whereas the underlying theory is a dynamic one. Therefore, by using available time series of the wage spread, the employment status of different skill groups, an indicator for technological advances and the labor market status, a reduced form VAR model is estimated and analyzed concerning the question how shocks in productivity (technology) and the labor market status determine the relative employment position and the wage spread. This allows us further to evaluate the theoretical outcomes of the theoretical model.

The remainder of this paper is organized as follows, section two presents stylized facts of the observed employment pattern. Section three presents the results of a time series examination for the U.S. and German economies, sections four and five outline the market structure and the equilibrium solution of the model, in section six we discuss the obtained results and section seven concludes.

2 Some Stylized Facts

As outlined above, a general explanation that coincides with the observed pattern of the employment status of different kinds of workers is the hypothesis of the so-called skill-biased technological change, i.e. that new technologies increase the demand for skilled workers and lower the demand for low skilled workers although the supply of skilled workers increased (see e.g. Autor et al. (1998), Katz and Autor (1999), or Acemoglu (2002)). Recently, the increased investment in information and communication technologies are, in general, assumed as such a major technological advance. The most important indicator of the existence of skill biased technological change is the increase of the wage spread between high and low skilled workers. Table 1 below, summarizes the main arguments of the SBTC - hypothesis for four

OECD countries. It is obvious that most of the variation in unemployment rates is found for the group of low skilled workers, whereas the unemployment rate for high skilled is rather constant or decreasing. Furthermore, for any country we find an increase in the supply of high skilled workers as well as a constant or increasing pattern of the wage spread.[7]

Table 1: Education, Employment and Demand for Skills

	Unemployment				Labour Force Participation			Supply and Demand for Skills		
	total	less secondary	upper secondary	tertiary	less secondary	upper secondary	tertiary	degrees in tert. educ.	wage spread OECD[a]	wage spread own calc.
France										
1971-82	–	—	—	—	—	—	—	—	—	—
1982	7.7	—	—	—	—	—	—	8.3	1.94	—
1988	9.9	—	—	—	—	—	—	11.8	1.99	—
1995	11.6	14.0	8.9	6.5	60.3	82.8	87.7	—	1.99	—
2002	8.9	11.8	6.8	5.2	65.7	81.5	89.1	12.0	—	—
Germany										
1971-82	3.1	—	6.4	1.7	—	—	—	—	—	—
1982	5.7	—	—	—	—	—	—	7.4	1.63	1.49
1988	6.2	13.7	6.9	7.2	45.8	61.9	78.8	9.4	1.62	1.51
1995	8.2	13.3	7.9	4.9	56.8	77.1	88.5	13.0	1.61	1.50
2002	8.7	15.3	9.0	4.5	60.1	77.3	87.5	13.0	—	1.54
U.K.										
1971-82	5.0	—	7.5	2.4	—	—	—	—	—	—
1982	10.3	—	—	—	—	—	—	12.0	1.74	—
1988	8.7	13.1	7.4	6.7	75.5	80.5	87.3	18.3	1.82	—
1995	8.7	12.2	7.4	3.7	61.8	82.1	88.8	—	1.87	—
2002	5.1	8.5	4.1	2.4	57.8	82.7	90.0	18.0	—	—
U.S.										
1971-82	4.9	—	7.8	2.0	—	—	—	—	—	—
1982	9.7	—	—	—	—	—	—	16.6	1.79	1.66
1988	5.5	10.1	5.9	3.0	43.8	69.9	78.2	21.5	1.88	1.81
1995	5.5	10.0	5.0	2.7	59.8	79.1	88.2	24.0	2.10	1.98
2002	5.8	10.2	5.7	3.0	63.5	78.5	85.7	28.0	—	2.00

Sources: Greiner et al. (2004), Nickell and Bell (1996), OECD (1989), OECD (1993), OECD (1996), OECD (2003), OECD (2004)

[a] Measured as ratio of the D9/D5 earnings.

Although table 1 might lead to the conclusion that the considered variables underly a steady evolution, it is shown by figures 1 and 2 below that cyclical variations and business cycle frequencies are at hand. Furthermore, the two-tier hypothesis

[7] See appendix A for further information concerning the used data.

of Saint-Paul (1996) is verified, i.e. we observe a significant low variation in the unemployment rate for skilled workers than for unskilled workers.

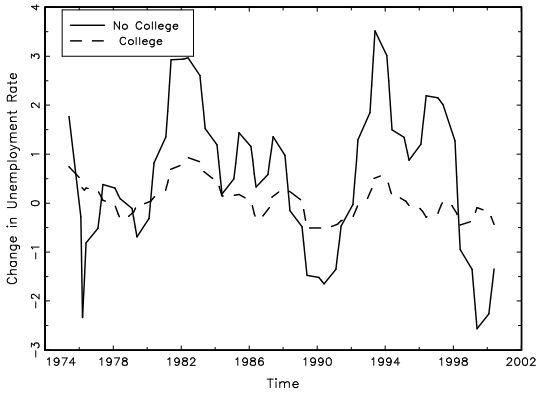

Figure 1: Germany, 1973.4-2004.4
Source: Institut für Arbeitsmarkt und Berufsforschung, own calculation

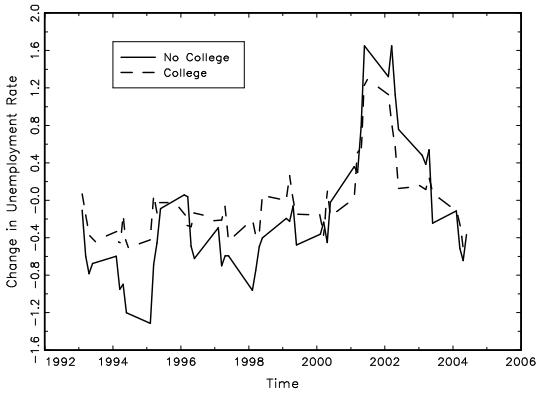

Figure 2: U.S., 1993.1-2004.4
Source: U.S. Bureau of Labor Statistics own calculation

Concerning the main indicator of skill-biased technological change, the increase of the wage differential, the time series of the wage spread (figures 3 and 4) indicates a cyclical pattern at business cycle frequencies, too.

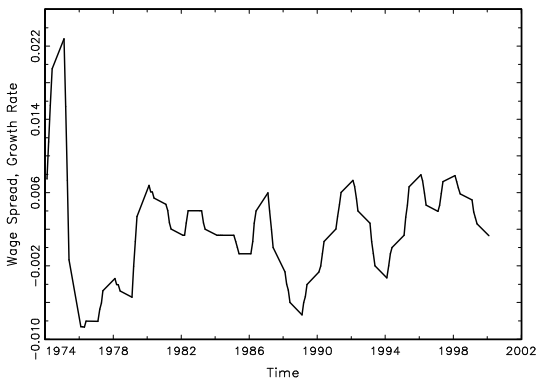

Figure 3: Germany, 1973.4-2004.4
Source: Federal Statistical Office Germany, own calculation

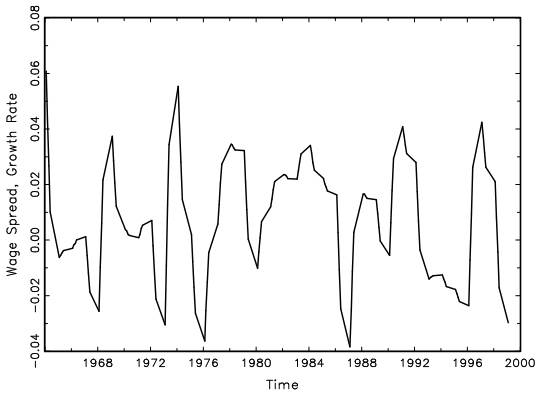

Figure 4: U.S., 1963.1-2004.4
Source: U.S. Bureau of the Census, CPS March 2003 own calculation

Beside the evidences of supply and demand shifts for different types of workers, labor market institutions can not be neglected in the analysis. The bargaining strength of trade unions and the social security system which determines the reservation wages of unemployed workers are generally treated as important institutional characteristics of labor markets. Table 2 below outlines the bargaining strength of the workers measured by union density, i.e. the ratio of employees organized in

trade unions per total employees, and the coverage of centralized wage bargaining. Furthermore, the measures by Dolado et al. (1996) outline the generosity of the social benefit system.

Table 2: Union Density, Bargaining Coverage and Minimum Wages

Year	U.S.	U.K.	Germany	France
		Trade Union Density		
1960	0.29	0.45	0.35	0.20
1980	0.23	0.56	0.35	0.19
1995	0.15	0.37	0.27	0.10
2002	0.13	0.31	0.25	0.10
		Bargaining Coverage		
1980	0.26	0.70	0.91	0.85
1995	0.18	0.47	0.92	0.95
2002	0.14	0.33	0.67	0.93
		Minimum Wages[a]		
	0.39 (1993)	0.40 (1993)	0.55 (1991)	0.50 (1993)

Source: Bierhanzl and Gwartney (1998), Dolado et al. (1996), OECD (2004)

[a] Minimum wages as a fraction of average earnings (Dolado et al. (1996): 321).

Although labor market institutions are important for the labor market outcome, it is obvious that the impact of labor market institutions decreased during the 1990's, in particular for the German economy.

3 Empirical Analysis

The main indicator of skill biased technological change is, as for example outlined by Acemoglu (2002), the increased wage differential between high and low skilled workers after a rise in the supply of skilled workers. In this section we try to examine the dynamic effects as outlined above within an empirical framework.

The above mentioned relation is captured by the following equation which relates the spread of wages, w_i, earned by workers of different skill groups, n_i with $i =$ (s)killed, (u)nskilled, to variables describing technological advances as well as the relative supply of skilled workers. Following the approaches by Murphy et al. (1998) or Greiner et al. (2004) and assuming a CES production technology, this relation

can be written as follows (see, for example, eqn. (26), below):

$$w^{\text{sp}} = \frac{w_t^s}{w_t^u} = \frac{\gamma}{1-\gamma} \cdot {z_t}^{(\varepsilon_s - \varepsilon_u)\sigma} \left(\frac{n_{s,t}}{n_{u,t}}\right)^{-\frac{1}{\sigma}}, \tag{1}$$

where γ denotes the income share of each type of labor, z_t gives the level of technology, $\varepsilon_s, \varepsilon_u$ determine an external effect of technology on the productivity of each type of labor and σ denotes the elasticity of substitution between both types of labor services. Rewriting eqn. (1) in logarithms a linear representation of the wage spread is obtained

$$\hat{w}^{\text{sp}} = \hat{\beta}_0 + (\xi_h - \xi_u)\hat{x}_t - \frac{1}{\sigma}\hat{n}_t, \tag{2}$$

with $\hat{\beta}_0 = \ln(\frac{\gamma}{1-\gamma})$, $\hat{z}_t = \ln(z_t)$ and $\hat{n}_t = \ln(n_{s,t}) - \ln(n_{u,t})$. Variations of equation (2) are at the center of many empirical examinations, for example by Katz and Murphy (1992), Katz and Autor (1999), or Krusell et al. (2000).

In order to derive a dynamic framework, equation (2) will be rewritten as a VAR representation, which we will be specified and estimated with a indicators of technological change and the state of the labor market. With the obtained estimations we derive impulse response functions to simulate the effects of an innovation in the supply of skilled labor and technology on the wage spread. Finally, the aggregate vacancy - unemployment ratio, θ_t will be considered as an indicator of the labor market position as well as the influence of wage setting institutions.

A general reduced form VAR representation of equation (2) reads as follows,[8]

$$\begin{pmatrix} \hat{w}^{\text{sp}} \\ \hat{n}_t \\ \hat{x}_t \end{pmatrix} = A_0 + \sum_{i=1}^{p} A_i \begin{pmatrix} \hat{w}^{\text{sp}}_{t-i} \\ \hat{n}_{t-i} \\ \hat{x}_{t-i} \end{pmatrix} + B\theta_t + \begin{pmatrix} \epsilon_{w,t} \\ \epsilon_{n,t} \\ \epsilon_{x,t} \end{pmatrix}, \tag{3}$$

where A_0 denotes a $j \times 1$ vector of intercept terms as well as A_i, for $i = 1, ..., p$, are $j \times j$ are matrices of coefficients of endogenous lagged variables. Note that, j equals the number of assumed variables. Furthermore, B denotes the matrix of coefficients of the exogenous variable θ_t.

The variable of technological change is measured by the index of labor productivity. In this analysis labor productivity is measured as output per employee rather than output per hour. Although the latter measure should be used, output per employee is taken because of the availability of comparable data sets.[9] In addition,

[8] A detailed description of estimating VAR models can be found in Hamilton (1994) or Lütkepohl and Krätzig (2004).

[9] The data are based on own calculations (wage spread, relative employment) as well as on data taken from the OECD Statistical Compendium, OECD Economic Outlook, 2005. A detailed description of the data used in this section can be found in appendix A.

the above VAR is extended by the so-called labor market tightness, i.e. the vacancy - unemployment ratio.[10] Although this ratio does not measure the influence of labor market institutions directly, it is an important variable determining the bargaining power when during negotiation procedures and also captures structural imbalances.

The properties of the time series are summarized in table 9 (Appendix B). The results indicate non-stationary behavior of the time series in levels, whereas no unit roots are not found when first differences are taken into account. For the so-called labor market tightness, measured by the v/u - ratio, the hypothesis of a unit root is generally rejected. Although the existence of unit roots allows for cointegration of the variables, however, we follow the approach outlined by Sims et al. (1990) and specify and estimate VAR models in levels. This leads to inefficient but consistent estimates, whereas a false specification of cointegration relations might lead to inconsistent estimates.

For the subsequent estimations of the VAR model as described by eqn. (3), a general lag length of two is chosen. This seems sufficient because a higher lag order goes hand in hand with unstable impulse response functions which indicates overspecified models.[11] After estimating the respective models the innovations of each VAR are orthogonalized by using a Cholesky decomposition of the variance-covariance matrix. This representation allows, according to Sims (1980), the determination of impulse response functions which will be considered for the examination of the impacts of technological advances on relative employment and the wage spread.

According to Acemoglu (1998) an increase of the relative supply of skilled workers should decrease the wage premium in the short run whereas induced technological change inventive activities increases the demand for skilled workers in the long run and, therefore, leads to an increase of the wage premium.[12] In general, whether the hypothesis of skill biased technological change, as outlined by Acemoglu (1998), is valid we should observe a negative response of the wage spread to a shock in the relative supply of skills. Furthermore, an innovation of economic activity or technological advances should lead after a while to an increase of the wage spread. By taking the v/u ratio as an exogenous indicator of the labor market position

[10] A reduced form VAR approach to examine macroeconomic policies under labor market frictions can be found, for example, in Yashiv (2004). In addition, more sophisticated VAR models of labor market flows can be found in Blanchard and Diamond (1989) or Balakrishnan and Michelacci (2001). In particular, the latter study concentrates on job creation and job destruction dynamics in main OECD countries.

[11] The proposed specifications of the VAR model are outline in table 10 in appendix B.

[12] Cf. Acemoglu (1998): 1057.

one should expect a negative correlation between the wage spread as well as the relative employment position and the v/u ratio. An increase of the v/u-ratio should strengthen the bargaining power of workers (and of the trade unions) which should lead to a constant or even negative response of the wage spread. An increase in the market tightness increases the probability to find a job for both types of workers. Because of the greater availability of unemployed low skilled workers, an increase in the latter ratio should lead to a higher increase of low skilled employment relative to the employment of skilled workers.

Table 3: Estimation Results, U.S. 1972.1-1998.4

Variable	Deterministic Terms		Endogenous lagged Variables			Exogenous Variable
	const.	Trend	$w_s/w_u(t-1)$	$n_s/n_u(t-1)$	$X(t-1)$	$v/u(t-1)$
w_s/w_u	**0.2417** (1.7164)	-0.00001 (-0.0423)	**1.7279** (25.448)	0.0287 (0.6434)	0.0666 (1.025)	0.0014 (0.9334)
				$t-2$		
			-0.7693 (-11.2743)	-0.0093 (-0.2319)	**-0.1187** (-1.7666)	
n_s/n_u	**-0.5220** (-2.2917)	**0.0021** (6.0350)	-0.0077 (-0.0696)	**1.4376** (19.8930)	-0.0311 (-0.2959)	**-0.0060** (-2.3850)
				$t-2$		
			-0.0061 (-0.5497)	**-0.6510** (-9.8833)	0.0468 (0.4420)	

t-statistics in parentheses.
Significance: 10%: 1.658; 5%: 1.980 (cf. Mood et al. (1974): 556.)

For the U.S., the results presented in table 3 show, at first, a constant and a significant trend in the wage spread. However, the impact of the relative supply of employees react in accordance to the theoretical explanation, i.e. a negative response in the period $t-1$ however sign changes when further lags are considered. On the other hand the evolution of the relative employment status is almost explained by lagged values of this variable.

The latter observation is also made for the German economy (see table 4, below). In contrast to the U.S., the intercept term and the time trend for the wage spread turned out to be significant for the German data. Furthermore, the relationships between inequality and relative employment behave similarly for both economies. In particular, a significant negative coefficient between the labor market status and relative employment is found for both economies.

Table 4: Estimation Results, Germany 1975.1-2000.1

Variable	Deterministic Terms		Endogenous lagged Variables			Exogenous Variable
	const.	Trend	$w_s/w_u(t-1)$	$n_s/n_u(t-1)$	$X(t-1)$	$v/u(t-1)$
w_s/w_u	**-0.0640** (-2.5274)	**-0.0001** (-2.4670)	**1.6610** (27.1022)	0.0049 (0.3380)	0.0102 (1.0539)	0.0002 (1.056)
				$t-2$		
			-0.6507 (-9.7961)	0.0055 (0.3839)	0.0053 (0.5525)	
n_s/n_u	0.0942 (0.7909)	**0.0003** (2.2767)	-0.0793 (-0.2751)	**1.6062** (23.4824)	-0.0394 (-0.8700)	**-0.0021** (-2.2964)
				$t-2$		
			-0.1214 (-0.3885)	**-0.7178** (-10.5888)	0.0215 (0.4725)	

t-statistics in parentheses.
Significance: 10%: 1.658; 5%: 1.980 (cf. Mood et al. (1974): 556.)

In a further step, the obtained estimation results are used to derive impulse response functions which outline the dynamic effects of innovations in selected variables.

Figures 5 and 6 below show the responses of an innovation in technology calculated for a 10-year period for the U.S. economy.[13]

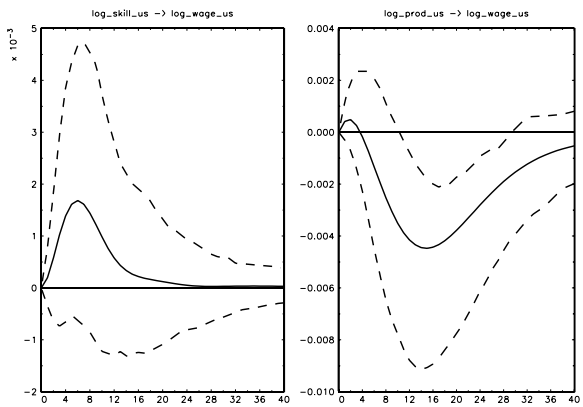

Figure 5: Responses of U.S. wage inequality

[13]Please note that the solid lines represent the point estimate of the impulse response function. The dashed lines show the 95% confidence interval, obtained from a simulation based Bootstrap-Distribution (1000 replications).

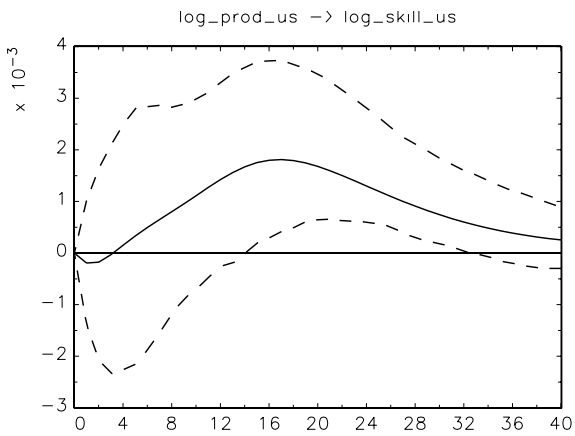

Figure 6: Responses of relative employment, U.S.

The main findings for the U.S. economy are that an increase in the relative number of skilled workers leads to a increase in the wage spread for ten quarters and which, however, turns negative afterwards (figure 5, left). This finding is consistent with the results shown by figure 6. There, an increase in technology leads to a increase in the relative employment position after the fourth period. When the response of the wage spread on a technology shock is considered (figure 5, right), only a small positive response is obtained, after the fourth period the response of inequality turns negative. However, the negative trend changes after the period of four years. In general, the empirical results for the U.S. economy are in line with the theoretical predictions of, for example,Acemoglu (1998). In particular, for the considered time interval, the so-called supply effect of an increase in the supply of skilled workers is reproduced by the empirical results.

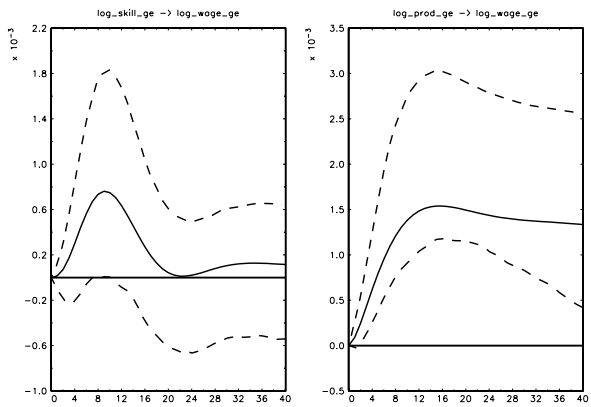

Figure 7: Responses of wage inequality, Germany

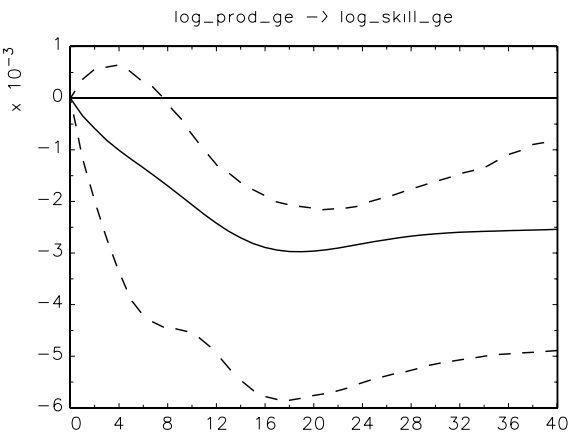

Figure 8: Responses of relative employment, Germany

In contrast to the U.S. the results for Germany report a positive response of wage inequality to an increase in the relative supply of skilled workers (figure 7) as well as a positive response of the wage spread on an increase in technology. However, because of the confidence intervals include the null after the forth year, negative responses cannot be excluded. Concerning the effects of an increase in technology, the positive effect on the wage spread is much more persistent than reported for the U.S. (compare figures 5 (right), 7 (right)). However, the same innovation leads to a reduction in the relative employment position of skilled workers (figure 8). The latter effect might be due to the fact that in Germany a successful institution of practical education exists, rather than in the U.S..

As shown by the empirical analysis, there is a different behavior of wage inequality and relative employment in response to advances in technology when we compare the U.S. and Germany. In the U.S. technology shocks lead to rather instantaneous improvements in employment, whereas we observe reactions in wages (and the wage spread) than in employment. The latter effect might be explained by the high bargaining power and the coverage of wage agreements in Germany, i.e. gains from improvements in productivity result in higher wages than in higher employment.[14] Therefore, it seems questionable whether a DGE framework with perfect labor markets, as for example assumed by Lindquist (2004), is able to account for the empirical observation.

[14]See, e.g. Blanchard and Wolfers (2000) for a survey on the impact of labor market institutions on continental European unemployment.

4 The Model

Market structure of the Model

The model discussed in this paper is based on the seminal work by Kydland (1984), Merz (1995) and on suggestions made by Cahuc and Zylberberg (2004) as well as Heckman et al. (1998). The model economy consists of two sectors, a household sector which supplies labor and physical capital to the production sector. The labor force is differentiated into two skill groups, high and low skilled workers, which are assumed to be imperfect substitutes in production. The production sector consists of many small firms using capital and both types of labor services in order to produce a single good which can be either consumed or invested. The market for final goods is characterized by perfect competition, whereas the labor market is characterized by search and matching frictions. It is assumed that jobs for high and low skilled workers are destroyed in any period at an exogenous rate $\psi_i \in (0,1)$ with $i = s, u$. Furthermore, we assume a two sided search process, i.e. both unemployed workers of each skill group (s=skilled, u=unskilled) and firms with vacant jobs seek for new job matches.

The Labor market

The economy's labor force is assumed to be constant and is normalized to one. Let $n_{i,t}$ denote the ratio of labor of the skill group $i = s, u$, i.e. $N = 1 = l_s + l_u$. Each type of labor can either be employed or unemployed, i.e. $l_i = h_i + u_i$. The employment of each skill group evolves according to

$$h_{s,t+1} = (1-\psi_s)h_{s,t} + M_{s,t} \tag{4}$$

$$h_{u,t+1} = (1-\psi_u)h_{u,t} + M_{u,t}, \tag{5}$$

where $\psi_i \in (0,1)$ denotes an exogenous rate of job destruction and $M_{i,t}$ gives the number of newly created jobs in period t. New job matches are created through a 'standard' matching technology,

$$M_i = M(s_{i,t}u_{i,t}, v_{i,t}). \tag{6}$$

For simplicity it is assumed that both skill groups are separated from each other, i.e. low skilled workers can not apply for high skilled jobs and vice versa. The matching technology given by eqn. 6 implies the following transition probabilities

from unemployment to employment and from an unfilled to a filled job vacancy of type i:

$$p_{i,t} = \frac{M_{i,t}}{s_{i,t}(1-h_{i,t})} \tag{7}$$

$$q_{i,t} = \frac{M_{i,t}}{v_{i,t}}. \tag{8}$$

The market tightness for each type of worker, θ_i, follows as

$$\theta_{s,t} = \frac{v_{s,t}}{(1-h_{s,t})} \tag{9}$$

$$\theta_{u,t} = \frac{v_{u,t}}{(1-h_{u,t})}. \tag{10}$$

With the definition $li,t = u_{i,t} + h_{i,t}$ the respective employment and unemployment rates of each skill group follow as $\tilde{h}_{i,t} = h_{i,t}/l_{i,t}$ and $\tilde{u}_{i,t} = u_{i,t}/l_{i,t}$, i.e.

$$\tilde{u}_{i,t} = 1 - \tilde{h}_{i,t}. \tag{11}$$

The household sector

We assume a representative household with many inhabitants. For simplicity, the total number of the household's members is normalized to one. The household chooses investment in physical capital, I_t, and the search intensities, $s_{i,t}$ of the respective skill group in order to maximize the present discounted value of its lifetime utility. Household's members receive income from lending capital to firms at the interest rate r_t and from having a fraction of both types of its members $n_{i,t}$ work at the respective wage rates $w_{i,t}$. The households maximization problem reads as follows:

$$U_t = \max_{c_t, s_{i,t}, k_{t+1}, h_{i,t+1}} \sum_{t=0}^{\infty} \beta^t U(c_t, h_{s,t}, h_{u,t}) \tag{12}$$

subject to

$$c_t + I_t + \sum_i \kappa_i(s_{i,t})(1-h_{i,t}) = \sum_i w_{i,t}h_{i,t} + r_t k_t \tag{13}$$

$$k_{t+1} = (1-\delta)k_t + I_t \tag{14}$$

$$h_{s,t+1} = (1-\psi_s)h_{s,t} + p_{s,t}s_{s,t}(1-h_{s,t}) \tag{15}$$

$$h_{u,t+1} = (1-\psi_u)h_{u,t} + p_{u,t}s_{u,t}(1-h_{u,t}), \tag{16}$$

where $c_t, k_t, r_t, h_{i,t}$ denote consumption, physical capital, the interest rate, and the respective type of labor. Furthermore, $s_{i,t}, \psi_i$ and $p_{i,t}$ represent the search intensity,

the rate of job destruction and the rate an unemployed workers finds a new job. The costs of an unemployed worker of type i for searching for a new job is given by the function $\kappa_i(s_{i,t})$. If a job is productive, the worker of type i receives a negotiated wage $w_{i,t}$ (see below). Furthermore, it is assumed that the different types of workers pool their incomes which leads to a perfect insurance against the loss of income during unemployment.

The production sector

Following Merz (1995) firms choose the plans for the amount of capital they rent from households and for the number of vacancies, $v_{i,t}$ they post at constant vacancy cost a_i in order to maximize the present discounted value of their stream of future profits. Firms sell their output y_t at a price that is normalized to one. The production factors, capital and labor are bought at the interest rate r_t and the wage rate $w_{i,t}$, respectively. The firm's decision problem follows as

$$\max_{k_t, v_t} E_t \sum_{t=0}^{\infty} \beta^t \lambda_t \Pi_t \tag{17}$$

subject to

$$h_{s,t+1} = (1-\psi_s)h_{s,t} + q_{s,t}v_{s,t} \tag{18}$$

$$h_{u,t+1} = (1-\psi_u)h_{u,t} + q_{u,t}v_{u,t}. \tag{19}$$

Note that Π_t denotes the firms profits, i.e.

$$\Pi_t = f(k_t, h_{s,t}, h_{u,t}, z_t) - \sum_i w_{i,t}h_{i,t} - r_t k_t - \sum_i a_i V_{i,t} \tag{20}$$

The production technology is assumed according to Heckman et al. (1998). This captures two important effects, first the assumption of imperfect substitution between the different kinds of labor, a rather standard assumption in the literature of skill biased technological change, and, furthermore, imperfect substitution between labor and physical capital. The latter assumption accounts for the fact that, in the short run, labor can not be substituted by capital immediately.[15] According to Greiner et al. (2004) the production technology is further augmented by positive externalities of technological change, $\varepsilon_s, \varepsilon_u > 0$,

$$f(\cdot) = z_t \left(\alpha \left(\gamma (z_t^{\varepsilon_s} h_{s,t})^{\sigma_1} + (1-\gamma)(z_t^{\varepsilon_u} h_{u,t})^{\sigma_1} \right)^{\frac{\sigma_2}{\sigma_1}} + (1-\alpha)k_t^{\sigma_2} \right)^{\frac{1}{\sigma_2}} \tag{21}$$

[15] See also Rowthorn (1999) for a study concerning imperfect capital labor substitution in business cycle models.

where z_t denotes a shock in technology which affects overall productivity as well as the individual productivity of each skill group due to an external effect which is captured by the assumption of $\varepsilon_i > 0$. Furthermore, α denotes the labor share of total income. The parameters σ_1 and σ_2 determine the substitution elasticities between both types of workers as well as between labor and physical capital.

The technology shock, z_t is assumed to follow a stationary stochastic process which is described by the following law of motion:

$$z_{t+1} = \omega z_t + \epsilon^z_{t+1}, \tag{22}$$

with $\epsilon^z_t \sim i.i.d.\ \mathcal{N}(0, \sigma^2_z)$ and $\omega \in [0, 1]$.

Wage Setting and Inequality

The wage is negotiated according to a Nash bargaining procedure once firms and workers meet in order to form a productive job. During this process firms and workers are considered as monopolists earning an economic rent if a job becomes productive. Therefore, this bargaining scheme allocates the rent surplus of a productive job between firms and workers.[16] For a worker of type i who matches to a firm, the value of a job is given by the real wage $w_{i,t}$ net of costs of search and disutility of work. For a firm, the value of a filled job follows from the difference between a worker's marginal product, the wages and the firm's advertising costs.[17]

The net surplus of the household is given by

$$W^h_i = w_{i,t} + \kappa_i(s_{i,t}) - u_{i_t}(c_t, h_{i,t}) + \frac{\kappa_{s_i,i}(s_{i,t})}{p_{i,t}}(1 - \psi_i - p_{i,t}s_{i,t}).$$

Note that the workers's surplus consists of the wage rate, the search costs of the current and the next period net the disutility of work. The net surplus of the firm is given by

$$W^f = f_{h_i}(\cdot) - w_{i,t} + \frac{a_i}{q_{i,t}}(1 - \psi_i).$$

The Nash bargaining criterion is given by

$$w_t = \text{argmax} \ \ \left(W^h_i\right)^{\phi_i}\left(W^f\right)^{1-\phi_i}, \tag{23}$$

[16] *"Hence a realized job match yields some pure economic rent, which is equal to the sum of the expected search costs of the firm and the worker. Wages need to share this economic (local monopoly) rent, in addition to compensating each side for its costs from forming the job."* See Pissarides (2000): 15.

[17] Please note that subscripts except i and $t, t+1$ denote partial derivatives.

where ϕ_i denotes the bargaining strength of the worker. The wage results as:

$$w_{i,t} = \phi_i \left[f_{h_i}(k_t, h_{s,t}, h_{u,t}, z_t) + \sum_i a_i \theta_{i,t} \right] + (1 - \phi_i) \left[\frac{U_{h_{i,t}}(\cdot)}{\lambda_t} - \kappa_i(s_{i,t}) \right]. \quad (24)$$

As in Merz (1995) the wage results as a weighted sum of the marginal product of labor net of advertising costs and the disutility of work corrected for foregone search costs.

The wage spread due to the skill differences between both types of workers follows as

$$\frac{w_h}{w_u} = \frac{\phi_h \left[f_{h_s}(\cdot) + a_s \theta_{s,t} \right] + (1 - \phi_h) \left[\frac{U_{h_s}(\cdot)}{\lambda} - \kappa_{s_s}(s_{s,t}) \right]}{\phi_u \left[f_{h_u}(\cdot) + a_u \theta_{u,t} \right] + (1 - \phi_u) \left[\frac{U_{h_u}(\cdot)}{\lambda} - \kappa_{s_u}(s_{u,t}) \right]} \quad (25)$$

For comparison, if we would consider a model with a perfect labor market wage inequality is given by:[18]

$$\frac{w_h}{w_u} = \frac{\gamma}{1 - \gamma} \left[\frac{z^{\varepsilon_h}}{z^{\varepsilon_u}} \right]^{\sigma_1} \left[\frac{h_u}{h_s} \right]^{1 - \sigma_1} \quad (26)$$

Comparing equations (25) and (26) it is obvious that wage inequality resulting in the recent model does not depend on the production technology, external effects of knowledge and the rate of substitution between different skill groups alone. An important determinant of the pattern of wage inequality is given by the bargaining power of workers, ϕ_i which governs the fraction of the firm's surplus is distributed to the worker. Furthermore, as can be seen easily, eqns (25) and (26) coincide in the case when ϕ_i converges to 1 and when no costs of vacancy creation would be assumed. Beside the fact, that the workers disutility of work and his search costs are introduced in the wage equation, an important factor which determines inequality (as well as the wage setting) is the workers bargaining power ϕ_i.

5 Equilibrium Solution and Calibration

According to Langot (1995) the symmetric general equilibrium solution is obtained as follows: at first the optimal job search and vacancy creation behavior is computed, furthermore the wage rate is determined within a Nash-bargaining framework. Second, market clearing conditions in the good and capital markets are imposed. However, because the wage is not the price which clears, for example a Walrasian labor

[18] A similar expression is obtained by Greiner et al. (2004).

market, the solution of this problem is not a Pareto optimum.[19] Please note, that due to the time consuming matching process on the labor market, this market is characterized by a stochastic rationing pattern, i.e. there is a positive probability $1-q(\theta_i)$ that a hiring firm does not find a worker and a probability $1-\theta_i q(\theta_i)$ that an unemployed worker does not find a vacant job position.[20] An equilibrium of this economy is a set of variables

$$\begin{aligned}\Omega_t &= \{k_{t+1}, h_{s,t+1}, h_{u,t+1}, s_{s,t}, s_{u,t}, p_{s,t}, p_{u,t}, q_{s,t}, q_{u,t}, M_{s,t}, \\ &\quad M_{u,t}, v_{s,t}, v_{u,t}, u_{s,t}, u_{u,t}, c_t, y_t, I_t, r_t, w_{s,t}, w_{u,t}, \theta_{h,t}\theta_{u,t}, z_t, \check{z}_t, \tilde{z}_t\}\end{aligned}$$

which is determined by the household's and the firm's Euler equations as well as the respective resource constraints.

The households maximization problem given by equations (12)-(16) lead to the following Euler equations

$$\beta E_t\Big\{\frac{U_c(c_{t+1})}{U_c(c_t)}(1+r_{t+1}-\delta)\Big\} = 1 \tag{27}$$

$$\begin{aligned}&\beta E_t\Big\{-U_{h_s}(h_{s,t}) + \lambda_{t+1}(w_{s,t+1}h_{s,t+1} + \kappa_s(s_{s,t+1}))+ \\ &\frac{\kappa_{h_s,s}(s_{s,t+1})}{p_{s,t+1}}\lambda_{t+1}(1-\psi_s - p_{h,t+1}s_{s,t+1})\Big\} - \frac{\kappa_{h_s,s}(s_{s,t})\lambda_t}{p_{s,t}} = 0\end{aligned} \tag{28}$$

$$\begin{aligned}&\beta E_t\Big\{-U_{h_u}(h_{u,t}) + \lambda_{t+1}(w_{u,t+1}h_{u,t+1} + \kappa_u(s_{u,t+1}))+ \\ &\frac{\kappa_{h_u,u}(s_{u,t+1})}{p_{u,t+1}}\lambda_{t+1}(1-\psi_u - p_{u,t+1}s_{u,t+1})\Big\} - \frac{\kappa_{h_u,u}(s_{u,t})\lambda_t}{p_{u,t}} = 0,\end{aligned} \tag{29}$$

note that λ_t denotes the Lagrange multiplier of the household's optimization problem.

The firm's decision problem which is given by equations (17) - (19) lead to

$$f_k(\cdot) - r_t = 0 \tag{30}$$

$$\frac{\lambda_t a_s}{\lambda_{t+1}q_{s,t}} - \beta E_t\Big\{f_{h_s}(\cdot) - w_{s,t+1} + \frac{a_s}{q_{s,t+1}}(1-\psi_s)\Big\} = 0 \tag{31}$$

$$\frac{\lambda_t a_u}{\lambda_{t+1}q_{u,t}} - \beta E_t\Big\{f_{h_u}(\cdot) - w_{u,t+1} + \frac{a_u}{q_{u,t+1}}(1-\psi_u)\Big\} = 0. \tag{32}$$

The equilibrium is determined by the household's and the firm's Euler equations (27)-(32), as well as equations (6), (4), (5), (7), (8), (9), (10), (11), (14), (21), (22), (24) and the aggregate resource constraint which is given by

$$c_t + I_t + \kappa_s(s_{s,t}) + \kappa_u(s_{u,t}) + a_s v_{s,t} + a_u v_{u,t} = y_t. \tag{33}$$

[19] Cf. Langot (1995): 297.
[20] Cf. Pissarides (2000): 7.

In order to solve and to calibrate the model we have to specify the functional forms of the household's utility function, the functions of search costs, the production and the matching technologies

$$U(c_t, h_{s,t}, h_{u,t}) = \frac{c_t^{1-\Phi}}{1-\Phi} - \frac{h_{s,t}^{1+\nu_s}}{1+\nu_s} - \frac{h_{u,t}^{1+\nu_u}}{1+\nu_u} \tag{34}$$

$$\kappa_s(s_{s,t}) = \bar{\kappa}_s s_{s,t}^{\mu} \tag{35}$$

$$\kappa_u(s_{u,t}) = \bar{\kappa}_u s_{u,t}^{\mu}. \tag{36}$$

The aggregate production function was already introduced by equation (21):

$$f(\cdot) = z_t \left(\alpha \left(\gamma (z_t^{\varepsilon_s} h_{s,t})^{\sigma_1} + (1-\gamma)(z_t^{\varepsilon_u} h_{u,t})^{\sigma_1} \right)^{\frac{\sigma_2}{\sigma_1}} + (1-\alpha) k_t^{\sigma_2} \right)^{\frac{1}{\sigma_2}} \tag{37}$$

in order to study the effects of skill augmenting technology shocks we rewrite eqn. (37) to

$$f(\cdot) = z_t \left(\alpha \left(\gamma (\check{z}_t^{\varepsilon_s} h_{s,t})^{\sigma_1} + (1-\gamma)(\tilde{z}_t^{\varepsilon_u} h_{u,t})_1^{\sigma} \right)^{\frac{\sigma_2}{\sigma_1}} + (1-\alpha) k_t^{\sigma_2} \right)^{\frac{1}{\sigma_2}} \tag{38}$$

where we assume that the two skill-augmenting technology shocks, $\check{z}_t, \tilde{z}_t$ follow uncorrelated stationary stochastic processes.

The matching technologies are specified analogue to Merz (1995) or Pierrard and Sneessens (2003)

$$M_{s,t} = v_{s,t}^{\rho_1} (s_{s,t} \cdot u_{s,t})^{(1-\rho_1)} \tag{39}$$

$$M_{u,t} = v_{u,t}^{\rho_2} (s_{u,t} \cdot u_{u,t})^{(1-\rho_2)}, \tag{40}$$

with $\rho_1, \rho_2 \in [0,1]$.

The calibration is chosen in accordance with the literature. The parameters of the utility function as well as search and advertising costs are taken from Merz (1995). One should note that it is assumed that firms have higher advertising costs if they look for high skilled workers and that low skilled workers have higher search costs than workers of the other skill group.

The levels of employment as well as the unemployment rates of the different skill groups, $\tilde{u}_i$, are chosen according to the empirical evidence as reported by table 1, i.e. total unemployment of the respective skill group follows as: $u_i = h_i \cdot \tilde{u}_i$. The elasticity of substitution between both types of labor services, σ_1, is chosen analogue to Heckman et al. (1998) who estimated an elasticity of 1.4, furthermore we follow their empirical results of a elasticity of substitution between capital and labor which

is close to 1. The external effects of new technologies are specified in line with the results of Greiner et al. (2004). The values of the worker's bargaining power ϕ_i are chosen in a way that both firms and work share the surplus of a productive job equally which coincides, in general, with the results of a centralized wage bargaining which is often found in continental European countries. The parameters of the matching technologies as well as the search costs are chosen in accordance to Merz (1995) and Pierrard and Sneessens (2003), in general we assume that a skilled worker has lower search costs than an low skilled worker and for the firm we assume the opposite case, i.e. it is more expensive to hire a worker with a university degree than a worker without such a degree. Although the quarterly job destruction rate for the German manufacturing sector is reported between 3-4%, lower job destruction rates (between 1 and 2 %)are chosen which are in accordance to German Panel Data estimates as well as the findings of Ridder and van den Berg (2003). There, aggregate job destruction rates are reported between 1-2%.[21] The destruction rates used for the calibration are chosen in accordance to the latter observation. Furthermore, we assume, for simplicity, that the productivity shocks follow the same autoregressive process.

Table 5: Parameter Settings

$\bar{h}_s$	$\bar{h}_u$	$\bar{\bar{u}}_s$	$\bar{\bar{u}}_h$	$\bar{z}, \bar{\bar{z}}, \bar{\bar{z}}$	α	β
0.25	$1 - \bar{N}_h$	0.05	0.10	1	0.64	0.99
δ	$\bar{R}$	Φ	γ	μ	ν_s, ν_u	$\bar{\kappa}_h$
0.025	$1/\beta$	0.5	0.5	1.0	0.8	0.025
$\bar{\kappa}_u$	ψ_s	ψ_u	$\sigma_1(\sigma_2)$	ρ_1	ρ_2	a_h
$2 \times \kappa_h$	0.01	0.02	0.3 (0.1)	0.7	0.7	$2 \times a_u$
a_u	ϕ_h	ϕ_u	ε_h	ε_u	$\omega_z, \omega_{\bar{z}}, \omega_{\bar{\bar{z}}}$	$\epsilon_z, \epsilon_{\bar{z}}, \epsilon_{\bar{\bar{z}}}$
0.025	0.5	0.5	1.5	1.0	0.95	0.007

For the subsequent analysis the steady state of the deterministic part of the model is computed numerically by a Newton-Raphson method provided by DYNARE[22]. The impulse response functions rely on a first order approximation of the stochastic model around its steady state.

[21] The measures for the manufacturing sector are based on job flow data taken from the Bundesagentur für Arbeit (WZ93/BA). Many thanks to Alfred Garloff for his suggestions concerning German job destruction rates.

[22] Dynare is a pre-processor and a collection of MATLAB or SCILAB routines which solve non–linear models with forward looking variables. See `http://www.cepremap.cnrs.fr/dynare/`. See Juillard (1996) for details.

6 Model Discussion

The first model we discuss in this section is a model without labor market frictions and also exhibits no wage bargaining.[23] In particular, this model follows the DGE model by Lindquist (2004). However, wage inequality is determined by skill-biased technology shocks in contrast to Lindquist (2004) who assumes capital-skill complementarity. In addition, we assume imperfect capital - labor substitution as in Heckman et al. (1998) (see eqn. (21)). This proceed avoids the introduction of different kinds of capital goods, like structures and equipment capital as in Lindquist (2004).

We first examine the effect of an overall technology shock (figure 9, solid line). This shock might be interpreted as the introduction of a general purpose technology which increases the productivity of both kinds of workers, however at different magnitudes. The increase in technology leads to an immediate positive response of output, consumption and the employment of both skill groups as well as the respective wages (not reported here). However, the impact of a neutral productivity shock on output is rather low. Significant higher responses are obtained obtained for shocks which increase the individual productivity of workers. However, the obtained output responses do not show any delayed adjustment processes as it should be expected, for example.

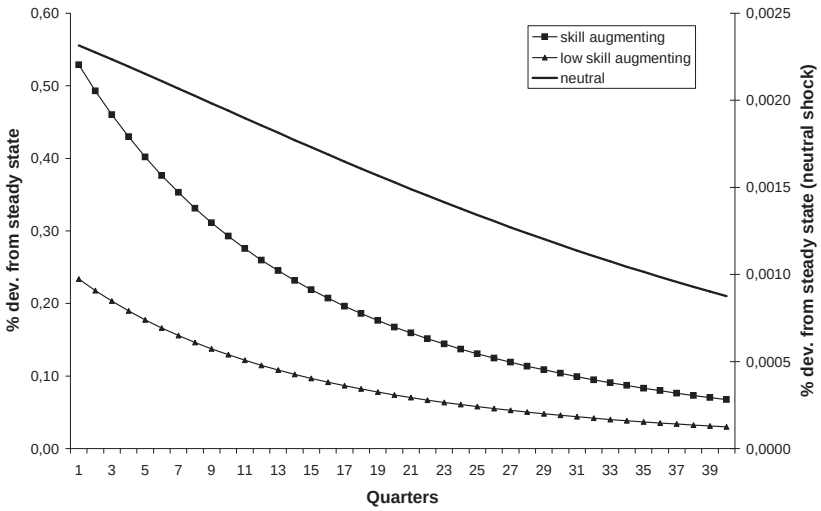

Figure 9: Model I, Output Responses of Asymmetric Technology Shocks

[23]Beside the work of Lindquist (2004) the general framework of the model basically refers to the primary work of Kydland (1984, 1995). A solution of this model in detail can be obtained from the author upon request.

Figures 10 and 11 below present the obtained impulse response functions of the wage spread and relative employment. In the case of a neutral productivity shock, the impact on skilled workers is higher than for low skilled workers, which leads to the positive response of relative employment (figure 10, solid line). Because of the supply effect, which decreases the marginal product of skilled workers, wage inequality responds negatively.

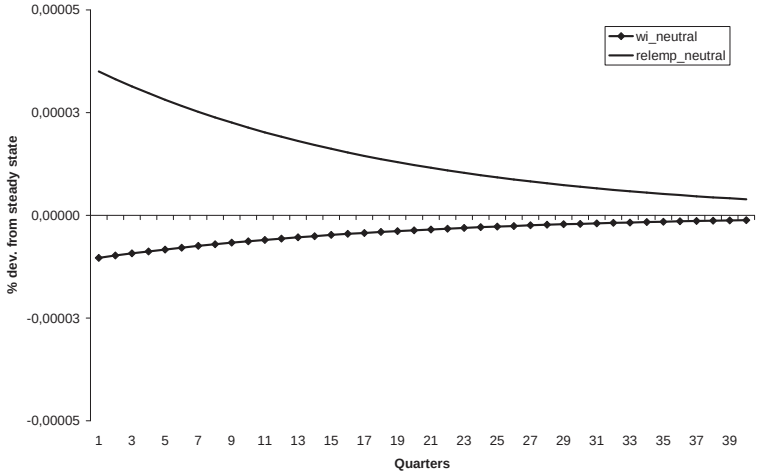

Figure 10: Model I, Inequality and Employment: neutral shock

Relative employment and the wage spread react as expected when biased technology shocks are considered. Figure 11 presents the obtained responses of an unanticipated increase in technology which either augments the productivity of skilled or unskilled workers, respectively.[24]

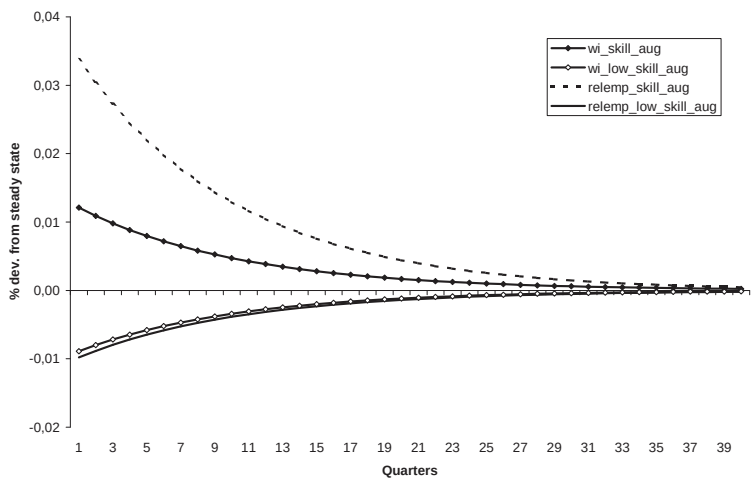

Figure 11: Model I, Inequality and Employment: skill-biased shocks

[24]The effects of the so-called 'low-skill bias' are suggested, for example, by Aghion (2002).

As shown above, a skill biased technology shock leads to an immediate increase in relative employment and in wage inequality. The opposite case is observed for a low-skill biased advance in technology. An interesting result is obtained for the response of the employment status of low skilled workers after a skill-biased technology shock (figure 12, below).

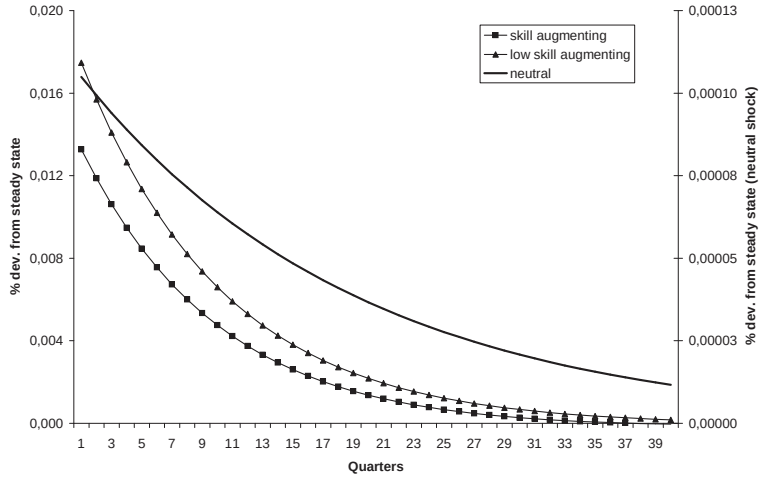

Figure 12: Model I, Low Skilled Employment

As shown above, a skill-biased technology shock leads to an immediate increase in low skilled employment, however, to a lesser extend than skilled workers. This response is explained by the immediate relative reduction of wages earned by low skilled workers. This effect is, in principle, observed for the U.S. labor market during the 1990's, where skill-biased technological advances did not has lead to a decline of low skilled employment.[25]

In general, the results are consistent with the empirical evidences concerning the assumption of skill-biased technical change for the U.S. In particular, the introduction of a skill-augmenting technology leads to a persistent increase in employment of skilled workers as well as in wage inequality. However, when the results of figures 9 - 12 are compared to the empirical findings (see figures 5-8), the obtained results do not exhibit a delayed response which are found empirically. The results of the model with perfect labor markets can be improved when labor market frictions, as described in section four, are introduced into the examination.

Figure 13 below presents the obtained responses of output after asymmetric ad-

[25]See, for example, Puhani (2005) for a discussion.

vances in technological progress.

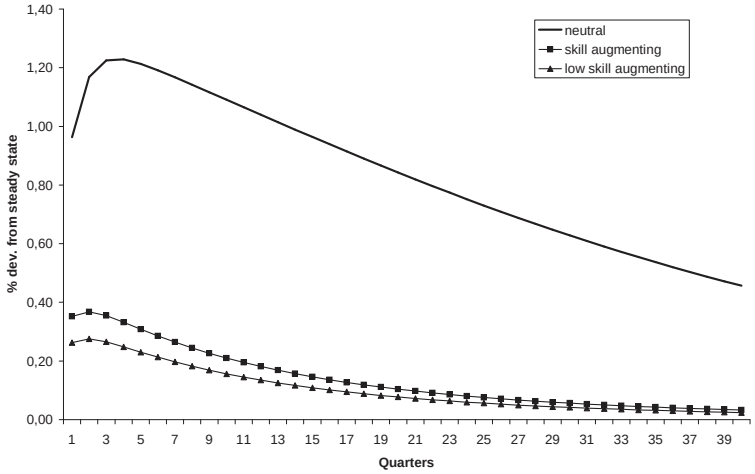

Figure 13: Model II, Output responses of Asymmetric Technology Shocks

In contrast to the assumption of perfect labor markets, the response of shows a delayed response after unanticipated shocks in technology. Furthermore, in contrast to the results presented in figure 9, the highest response of output is found for a neutral productivity shock. In this case an overall increase in productivity leads to higher job creation and employment for both types of workers. Due to increases in investment in physical capital a further increase in output is determined.

The main difference in the responses of relative employment between both models is found for the effects of a neutral productivity shock. As shown by figure 14, a neutral productivity shock leads to an immediate decrease of relative employment. In particular, this effect coincides with the empirical observation for the U.S. economy (see figure 6). The explanation of this response is that relative employment decreases because of the greater availability and lower recruitment costs of low skilled workers. Furthermore, each response displays a delayed or hump-shaped pattern which is also reported by the empirical findings.

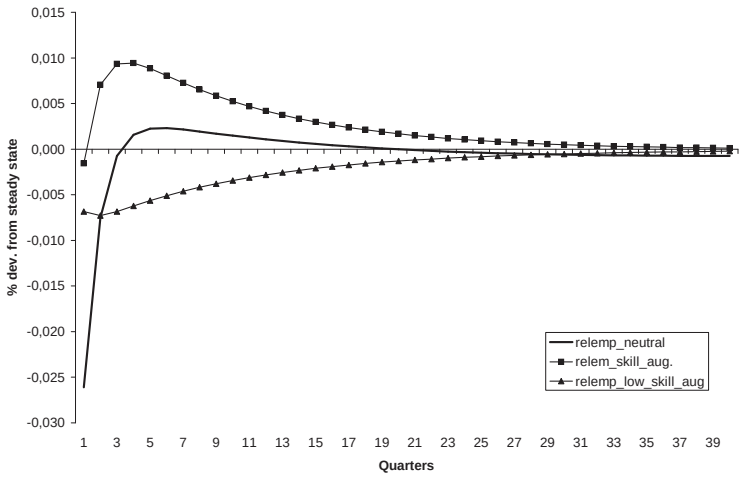

Figure 14: Model II, Responses of Relative Employment

When we consider the effects of asymmetric technology shocks on the wage spread (figure 15) we observe, at first, that a skill biased technology shock leads to the highest response of the wage spread. Furthermore, the response of the wage spread is more persistent than in the model with perfect labor markets where the wage spread is returned to its steady state level after 23 quarters. For a low skill biased shock the results are similar as in the model with perfect labor markets (compare figure 11). In contrast to the first model, a persistent increase in the wage spread is found for a neutral productivity shock (figure 15, solid line). In particular, such behavior is found empirically for the German data (see figure 7 right).

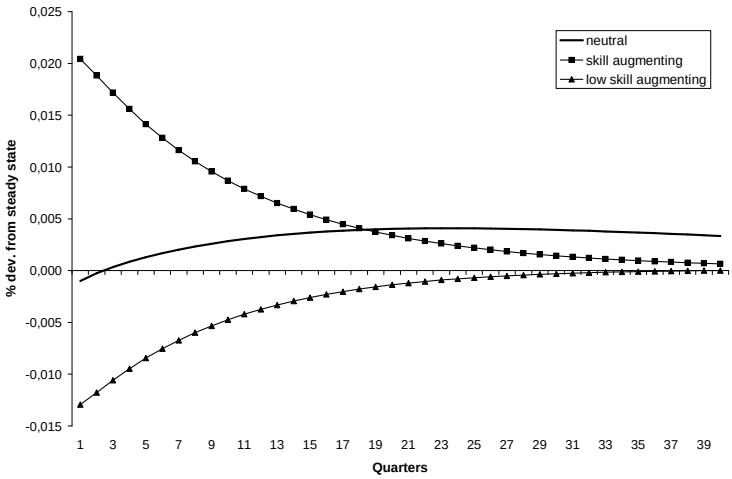

Figure 15: Model II, Responses of Wage Inequality

When we consider the effects of technological advances on the employment pattern of low skilled workers, the recent model displays the highest response of this variable after a neutral productivity shock which increases the productivity of both types of workers. A skill biased technology shock does lead to a rather small response of low skilled employment, only. At least the responses of a skill biased shock is more consistent with the empirical findings for continental European countries, where rather low positive responses of the employment pattern of low skilled workers is found during the so-called IT revolution. Furthermore, within the assumed search and matching framework, firms decide to hire workers when their productivity exceeds the firm's search costs. In the cases of skill or low skill biased shocks the productivity gains are not high enough to reach a similar response as after a neutral shock.

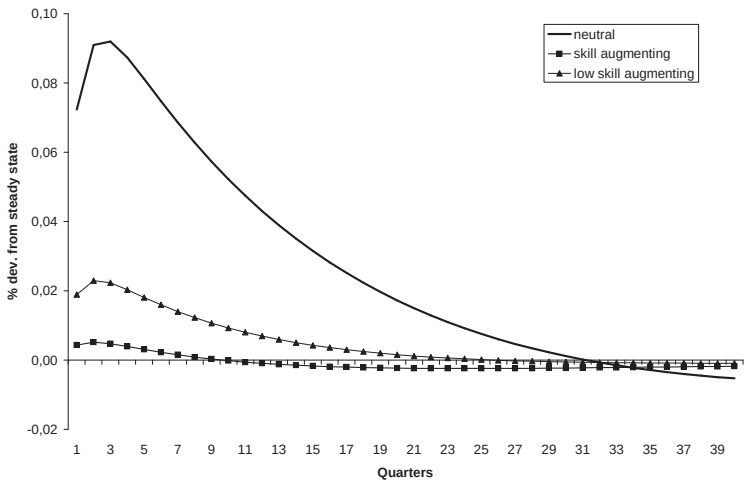

Figure 16: Responses of low skill employment

In a further step we raise the question whether the models are capable to reproduce basic facts of the business cycle. Table 6 below reports the empirical findings for the U.S. and Germany.

Table 6: Business Cycle Evidences

	relative Volatility	y	c	i	n_s	n_u	n_s/n_u	w_s	w_u	w_s/w_u
					U.S., 1964.1-1999.1					
					Correlation of observed Variables					
y	—	1.00	0.81	0.89	0.05	-0.22	0.23	0.37	0.33	-0.04
c	0.77		1.00	0.75	-0.01	-0.21	0.51	0.61	0.41	-0.27
i	2.44			1.00	0.02	-0.13	0.13	0.39	0.20	0.02
n_s	0.55				1.00	0.16	0.29	0.10	-0.12	0.27
n_u	1.22					1.00	-0.90	-0.27	-0.54	0.44
n_s/n_u	1.25						1.00	0.31	0.47	-0.31
w_s	0.95							1.00	0.71	0.15
w_u	1.16								1.00	-0.59
w_s/w_u	0.82									1.00
					Germany, 1973.1-2000.1					
y	—	1.00	0.78	0.73	-0.28	- 0.24	0.13	0.42	0.51	-0.22
c	1.47		1.00	0.62	-0.23	-0.19	0.10	0.27	0.18	0.09
i	2.24			1.00	-0.17	-0.13	0.06	0.33	0.33	-0.06
n_s	0.70				1.00	0.86	-0.45	-0.20	-0.11	-0.02
n_u	1.16					1.00	-0.85	-0.23	-0.18	0.01
n_s/n_u	0.67						1.00	0.20	0.17	-0.14
w_s	0.22							1.00	0.76	0.27
w_u	0.24								1.00	-0.38
w_s/w_u	0.16									1.00

In general we observe for both countries a rather low volatility of skilled workers (around 2/3 of the volatility of the GDP) and a rather high volatility of low skilled workers. Furthermore, wages in Germany are rather low volatile compared to the U.S. ($.40 < .90$). An important difference is observed for the volatility of the wage spread for Germany a rather stable wage spread is reported whereas we observe a volatile variable for the U.S..

The simulation results of the two models are reported in table 7 below.

Table 7: Business Cycle Properties of the Models

	relative Volatility	y	c	i	n_s	n_u	n_s/n_u	w_s	w_u	w_s/w_u
					Perfect Labor Markets					
					Correlation of simulated Variables					
y	—	1.00	0.72	0.91	0.94	0.93	0.94	0.98	0.92	-0.89
c	0.49		1.00	0.38	0.45	0.38	0.36	0.75	0.78	0.35
i	0.69			1.00	0.95	0.85	0.73	0.87	0.77	0.46
n_s	0.06				1.00	0.68	0.89	0.93	0.69	0.69
n_u	0.02					1.00	0.27	0.66	0.88	-0.06
n_s/n_u	0.07						1.00	0.81	0.37	0.94
w_s	0.08							1.00	0.84	0.61
w_u	0.07								1.00	0.08
w_s/w_u	0.01									1.00
					Labor Market Frictions					
y	—	1.00	0.78	0.90	0.80	0.81	-0.07	0.99	0.99	0.30
c	0.49		1.00	0.18	-0.04	0.03	0.05	0.68	0.65	0.30
i	0.77			1.00	0.96	0.98	-0.06	0.83	0.85	0.19
n_s	0.05				1.00	0.95	0.07	0.71	0.69	0.28
n_u	0.05					1.00	-0.16	0.72	0.77	0.01
n_s/n_u	0.19						1.00	0.03	-0.13	0.63
w_s	0.07							1.00	0.97	0.42
w_u	0.06								1.00	0.19
w_s/w_u	0.01									1.00

Comparing the reported correlations with the empirical findings, we find that the output correlation of the employment and wages are much higher than found in the data, although when labor market frictions are taken into account the correlation between output and employment is lower than in a model without frictions.

Furthermore, we find a negative correlation between output and low skilled employment in the data (table 6) which is not reproduced by the simulations results, also the a negative correlation between employment and wages is not found in the model. However, the high correlation of low and high skilled employment which is reported by the German data is reproduced in by both models. Also, the model with search frictions reproduces the negative correlation between technology and relative employment found in the German data.

However, when comparing dynamic correlation coefficients between output, wage inequality and the relative employment ratio, we observe that the model with search frictions displays a delayed correlation between output and wage inequality and the relative employment position (see table 8 below). In particular, this delayed correlation is evident for the U.S. and Germany.

Table 8: Dynamic Correlations

	Wage Inequality				
	$t-1$	t	$t+1$	$t+2$	$t+4$
U.S.	-0.14	-0.04	0.09	0.20	0.23
Germany	-0.29	-0.22	-0.05	0.17	0.41
RBC	-0.86	-0.89	-0.81	-0.74	-0.66
Search	0.28	0.30	0.31	0.31	0.30
	Relative Employment				
	$t-1$	t	$t+1$	$t+2$	$t+4$
U.S.	0.29	0.23	0.13	0.01	-0.22
Germany	-0.07	0.13	0.16	0.14	-0.06
RBC	0.91	0.95	0.88	0.81	0.68
Search	-0.11	-0.07	0.06	0.10	0.08

All in all the ability of the models to reproduce some facts of the business cycle is mixed. The model with perfect labor markets particularly overstates the correlation between variables whereas the model with search frictions understates the variability as well as the correlation of some variables. However, the model with search frictions is, in general, able to reproduce a delayed correlation between output and the wage spread and the relative employment position.

7 Concluding Remarks

Although the capability of the analyzed models to reproduce business cycle facts has to be improved, important insights concerning the transmission process of technological change under the assumption of labor market frictions and the effects on employment and wages could be derived.

In particular it could be shown by the comparison of the two models, that reasonable impulse responses, i.e. the delayed response of labor market variables due to technological innovations, require a certain degree of labor market imperfection. In particular, labor market institutions prevent the adjustment of wages which led to the persistent response of wage inequality in the model with search frictions.

Concerning the unemployment pattern of low skilled workers, the implications of the models are twofold. First, the demand for low skilled labor depends on the productivity of skilled workers as well as the economic position of the economy. Second, the employment status of low skilled workers can be enhanced due to advances in low-skill augmenting technology (as well as better schooling, etc.), however, the impact of such a policy is affected by labor market frictions. The results show, that

an increase in the productivity of low skilled workers generates a higher employment status of this group in a frictionless economy, whereas under labor market frictions the effects are rather low.

Although, a detailed consideration of rigid institutions due to high reservation wages or generous social benefit systems is left for future research the results of this paper show a possible way to examine the outcomes of technological advances under the existence of labor market frictions.

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A Data

- The U.S. unemployment data (figure 2)are taken from the Bureau of labor statistics (www.bls.gov) and are based on monthly observation. The German data are taken from the "Zahlen-Fibel" published by the Institut für Arbeitsmarkt und Berufsforschung (IAB) (www.iab.de) and are based on annual observations. In the latter case the quarterly data are obtained from linear interpolation. For both countries the quarterly real GDP is taken from the OCED Main Economic Indicators.

- Employment of high and low skilled workers:
  Based on annual data for the U.S. and Germany which are linear interpolated in order to obtain quarterly data. For the U.S., the data are taken from 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. and 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.
  For Germany, the data are taken from

- Federal Statistical Office Germany, *Fachserie 1, Bevölkerung und Erwerbstätigkeit, Reihe 4.2.1, Struktur der Arbeitnehmer*, Metzler - Poeschel, Wiesbaden, various issues since 1978 and *Fachserie 16, Löhne und Gehälter, Reihe 2.2 und 2.1*, Metzler - Poeschel, Wiesbaden, various issues since 1978. See also Greiner et al. (2004).

- tertiary education:
  The values for 1980 / 1989 are measured as the proportion of the population with a university degree (cf. OECD (1993): 172). The 2002 values are measured as percentage of population (age group 25-64) that has attained a tertiary type A or an advanced research program in 2001 (Cf. OECD (2003)).

- wage spread:
  Note that the German data refer to the West German manufacturing sector, only. However, a similar behavior of aggregate wage data is found by Fitzenberger (1999). For the U.S. the Data are taken from the CPS and show the ratio of wages for workers which some college degree to workers with a high school degree. For further details see Greiner et al. (2004).

B Time Series Tests and VAR Specification

Table 9: Testing for Unit Roots

	U.S., 1972.1-1998.4			Germany, 1975.1-2000.1		
	Deterministic		ADF	Deterministic		ADF
Variable	Terms	Lags	Test Statistic	Terms	Lags	Test Statistic
w_s/w_u	constant, trend	2	-2.3544	constant, trend	2	-3.0549
$\Delta w_s/w_u$	constant	1	-4.2355	constant	1	-2.3139
n_s/n_u	constant, trend	2	-4.3566	constant, trend	2	-2.8551
$\Delta n_s/n_u$	constant	1	-6.1377	constant	1	-4.5677
LP	constant, trend	2	-2.5671	constant, trend	2	-2.3649
ΔLP	constant	1	-5.3564	constant	1	-8.4994
v/u	constant, trend	2	-3.3264	constant,trend	2	-20.5764
$\Delta v/u$	constant	1	-4.8278	constant	1	-8.1193

McKinnon Critical Values:

	1%	5 %	10 %
levels	-3.96	-3.41	-3.13
1st. diff.	-3.43	-2.86	-2.57

The lag length of the VAR models for the U.S. and German economies are determined by using the general information criteria.[26]

Table 10: VAR Specifications

Information criteria	Variables (intercept and linear time trend included) U.S., 1970.1-1998.4 w_s/w_u n_s/n_u LP	Germany, 1973.1-2000.1 w_s/w_u n_s/n_u LP
AIC	10	2
FPE	10	2
HQ	2	2
SC	2	2

AIC: Akaike Information Criterion; FPE: Forecast Prediction Error; HQ: Hennan-Quinn; SC: Schwarz Criterion

[26] A detailed description of the specification tests can be found in Lütkepohl (2004):110 ff..