Heterogeneous Labor, Labor Market Frictions and the Business Cycle Theory and Empirical Evidence for the U.S. and Europe *

by

Jens Rubart[‡]

Darmstadt October 13, 2005

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. exhibits high rates of economic performance and low unemployment rates, whereas continental European countries possess low economic growth and high unemployment rates.

Based on the findings of Lindquist (2004) that the relative demand for skilled workers (measured by 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 with 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 and the demand for the different kinds of labor. In particular, the latter assumption enables us to control for stylized facts of continental European labor markets.

By confronting our theoretical results 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. Furthermore, the findings of Lindquist (2004) are improved for European labor markets.

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

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

---

*Many thanks to Willi Semmler, Volker Caspari and Günther Rehme for their valuable comments. Of course, all remaining errors are my own.

‡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. Whereas 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 is referred to 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 skill groups (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 with a 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. One could extend this hypothesis by following 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 is 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 investments 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] Beside the skill mismatch, i.e. the decreasing demand for low skilled workers, wage rigidities and a certain degree of labor market inflexibility wages for low skilled workers were

[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 to adjust downwards which led to the increase in the unemployment rate of low skilled workers.[5] However, as pointed out by Nickell and Bell (1996) time phases exist in which both unemployment of high and low skilled workers tend to increase, an observation which does not coincide with thy hypothesis of skill biased technological change, *... the unemployment rates for both groups have risen. This suggests that the countries concerned have also been subject to adverse shocks that are neutral as regards skill .. .*[6] By following the findings by Nickell and Bell (1996) the transmission mechanism of technological advances to the employment status of different types of workers has to be examined more extensively.

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. In general we combine the hypothesis of skill biased technological change as well as the assumption of search and matching frictions on the labor market within a dynamic general equilibrium (DGE) model of the business cycle. This proceed allows to examine 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 implication is widely discussed by Acemoglu (1999), Mortensen and Pissarides (1999) or in a recent paper by Hornstein et al. (2005). However, a concentration on the long-run impact of SBTC (as in Acemoglu (1999)), or on partial equilibrium models like Mortensen and Pissarides (1999) which is 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. An explanation of the observed fluctuations of the wage spread and the variability of working hours of different types of workers within a DGE context is given by Lindquist (2004). Related lines of research can be found in the work by Ljungqvist and Sargent (1998), Albrecht and Vroman (2002), Gautier (2002) or Pierrard and Sneessens (2003). In particular, we extend the work by Gautier (2002) or Pierrard and Sneessens (2003) by introducing capital accumulation, labor - leisure choice of the households as well

[5] A recent study of the skill mismatch in OECD is given by Petrongolo and Manacorda (1999).
[6] Cf. Nickell and Bell (1996): 303.

as skill-augmenting technology shocks. The latter assumption allows 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, that means that skilled and unskilled workers can apply to skilled an unskilled jobs only. This assumption simplifies the analysis and is also in line with recent empirical evidences by Gottschalk and Hansen (2003). Furthermore, 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, 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 relative employment 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 which coincides with the diverse observation concerning 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 major technological advance. The main evidence of the existence of the SBTC hypothesis 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 main

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 assumption 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.

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

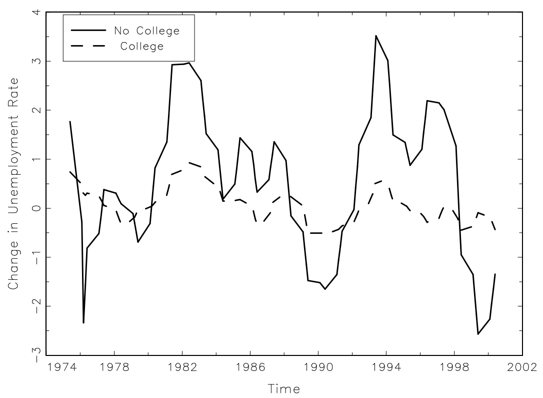

Figure 1: Germany, 1975.4-2004.4

Source: Institut für Arbeitsmarkt und Berufsforschung, own calculation

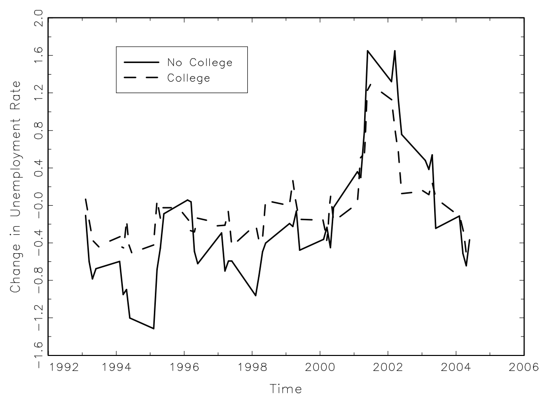

Figure 2: U.S., 1993.1-2004.4

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.

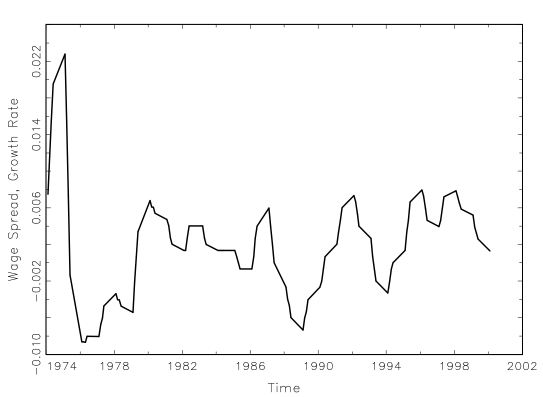

Figure 3: Germany, 1975.4-2004.4

Source: Federal Statistical Office Germany, own calculation

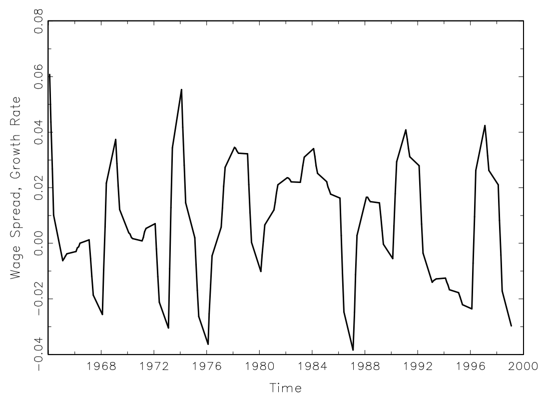

Figure 4: U.S., 1963.1-2004.4

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 within the analysis. Most important institutions concern the wage setting behavior, in particular the bargaining strength of trade unions, and the social benefit system which determine the reservation wages of unemployed workers. 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.

Under the assumption of a decreasing impact of labor market institutions on the one hand, and increasing technological advances on the other, the hypothesis of Krugman (1994) should be reconsidered. In particular, from the point of view how technological advances transmit to the labor market, especially to the employment record of different skill groups.

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 relation of interest in this section is 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:

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

where γ denotes the income share of each type of labor, X_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

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

with $\hat{\beta}_0 = \ln(\frac{\gamma}{1-\gamma})$, $\hat{x}_t = \ln(X_t)$ and $\hat{n}_t = \ln(n_{s,t}) - \ln(n_{u,t})$. Variations, as well as equation (2) are in 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 into a VAR representation, which we will be specified and estimated with several indicators of technological change and labor market indicators. With the obtained estimations we derive impulse response functions in order to simulate the effects of an innovation in the supply of skilled labor and technology on the wage spread. Finally, the aggregate vacancy - unemployment ration will be considered as an indicator of the labor market position as well as the influence of wage setting institutions.[8]

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

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

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 existence and availability of comparable data sets.[9] Furthermore,

[8] A reduced form VAR approach to examine macroeconomic policies under labor market frictions can be found in Yashiv (2004). A detailed description of estimating VAR models can be found in Hamilton (1994) or Lütkepohl and Krätzig (2004).

[9] The data are taken from own calculations and 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 which determines the bargaining power when during negotiation procedures and also captures structural imbalances.

Considering the results of table 8 (Appendix B) 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 allow for cointegration of the variables, we follow the approach by Sims et al. (1990) and specify and estimate VAR models in levels. This lead to inefficient but consistent estimates, whereas a false specification of cointegration relations might lead to inconsistent estimates.

For the subsequent estimations of the VAR models as specified above a general lag length of two is chosen. This seems sufficient because a higher lag order goes at 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. As outlined in the previous subsection allows this representation, according to Sims (1980), the determination of impulse response functions.

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, if the hypothesis of skill biased technological change, as outlined by Acemoglu (1998), is right 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 indicator of the labor market position the following response should be expected. 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. However, whether unemployment is caused

[10] 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 specification of the VAR models are outline in table 9 in appendix B.

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

by matching problems, i.e. the worker's abilities do not match the requirements of the offered job, skilled workers are in advance to low skilled workers which should lead (because of the bargaining strength) to an increase in inequality.

Table 3: Estimation Results, U.S. 1970.1-1998.4

Variable	Deterministic Terms		Endogenous lagged Variables			
	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	0.180 (2.880)	0.001 (3.664)	1.684 (28.518)	-2.265 (-2.757)	0.003 (1.293)	0.015 (0.177)
			$t-2$			
			-0.758 (-12.816)	1.774 (2.097)	-0.002 (-1.074)	-0.040 (-0.512)
n_s/n_u	-0.0054 (-0.981)	0.0003 (1.011)	0.0022 (0.412)	1.6110 (21.945)	0.0002 (1.116)	-0.0144 (1.1895)
			$t-2$			
			-0.004 (-0.741)	-0.6449 (-8.531)	-0.00003 (-0.133)	0.0106 (1.511)

t-statistics in parentheses.

For the U.S., the results presented in table 3 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, however, for relative employment the intercept term as well as a time trend turn out to be significant, too. In contrast to the U.S., the supply of relative skills does not exhibit a significant relation to the wage spread. However, the status of the labor market exhibits a positive relation to the wage spread.

Table 4: Estimation Results, Germany 1973.1-2000.1

Variable	Deterministic Terms		Endogenous lagged Variables			
	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	0.045 (1.435)	-0.00003 (-0.782)	1.726 (28.257)	0.001 (0.037)	0.0001 (0.528)	-0.0014 (-1.127)
				$t-2$		
			-0.766 (-11.931)	0.007 (0.185)	0.00004 (1.861)	0.002 (1.864)
n_s/n_u	0.1483 (2.4765)	0.0002 (2.4761)	-0.0841 (-0.726)	1.6130 (23.231)	-0.0004 (-1.162)	-0.001 (-0.431)
				$t-2$		
			0.0309 (0.253)	-.0708 (-10.322)	0.0023 (0.626)	-0.0009 (-0.414)

t-statistics in parentheses.

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

Figures 5 and 6 below show the responses calculated for a 10-year period of innovations in economic activity as well as technological advances based on the VAR model outlined in table 3.[13]

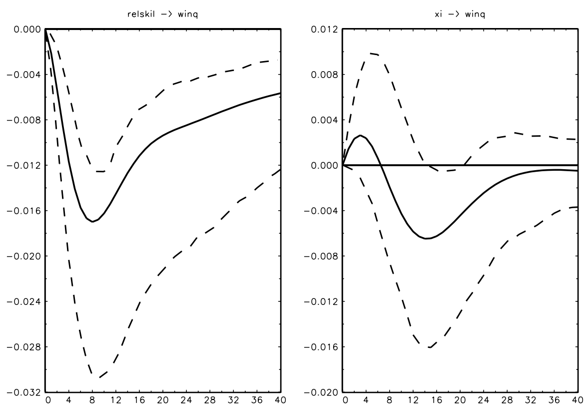

Figure 5: Responses of U.S. wage inequality

[13]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).

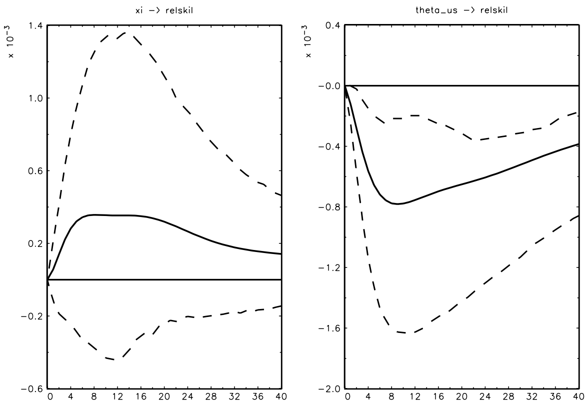

Figure 6: Responses of relative employment, U.S.

The main findings for the U.S. economy are that innovations, i.e. an increase, in the supply of skills lead to an immediate decrease of the wage premium, as for example predicted by Acemoglu (1998). Furthermore, an innovation in technological change lead to an increase in the wage premium. However, this effect disappears after eight quarters and turns negative for the rest of the examined time period (figure 5).

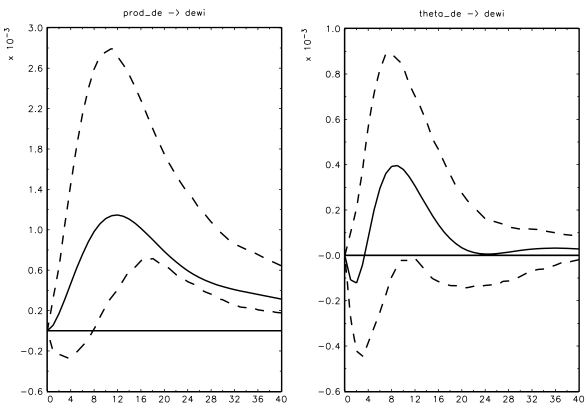

Figure 7: Responses of wage inequality, Germany

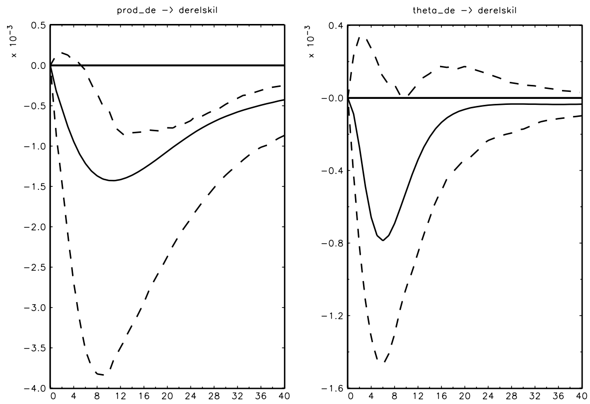

Figure 8: Responses of relative employment, Germany

Similar to the results for the U.S. economy wage inequality in Germany responds negatively to a positive supply effect of skilled workers, although the response is not as significant as observed for the U.S.. However, an increase in technology leads also to an increase in wage inequality, (`prod_de` $\rightarrow$ `dewi`). However, the same innovation leads to a reduction in the relative employment of skilled workers, or to an increase of the employment of lower skill groups. 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.. Furthermore, because of the bargaining system and possible insider effects, a positive innovation in the labor market position lead to a further increase of wage inequality, whereas the respective response is negative for the U.S.

Finally, when the labor market tightness is included within the regression equation. This variable highlights the bargaining power of wage setting institutions, i.e. the v/u ratio is positively related to the worker's bargaining strength. For the subsequent examination I treat the v/u - ratio as a further endogenous variable, although it is not a part of the original equation of the wage spread. Otherwise, this assumption seems reasonable because an indicator of the relative bargaining strength is of course related to the wage setting mechanism and, furthermore, as will be shown below the pattern of relative wages and employment is discussed in model frameworks where endogenous wage bargaining is an important mechanism.

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 which require 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

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

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

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,

$$M_i = M(S_{i,t}U_{i,t}, V_{i,t}). \quad (6)$$

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:

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

$$q_{i,t} = \frac{M_{i,t}}{v_{i,t}}. \quad (8)$$

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

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

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

Let $\tilde{h}_{i,t} = h_{i,t}/l_{i,t}$ and $\tilde{u}_{i,t} = u_{i,t}/l_{i,t}$, then the unemployment rate of each type of worker is follows as:

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

The household sector

We assume a representative household with a large number of inhabitants which 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 their life-time utility. Households 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:

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

subject to

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

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

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

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

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 analogue to Heckman et al. (1998). This production technology captures two important effects, first it captures the assumption of imperfect substitution between the different kinds of labor, a rather standard assumption in the literature of skill biased technological change. Furthermore, imperfect substitution between labor and physical capital is taken into account, too. The latter assumption accounts for the fact that, in the short run, labor can not be substituted by capital immediately.[14]. According to Greiner et al. (2004) the production technology is further augmented by positive externalities of technological

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

change, $\varepsilon_s, \varepsilon_u > 0$,

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

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:

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

with $\epsilon_t^z \sim i.i.d.\ \mathcal{N}(0, \sigma_z^2)$ 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.[15] 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 costs of search and disutility of work. On the other hand, the firm's value of a filled job follows from the difference between a worker's marginal product, the wages and the firm's advertising costs.[16]

The net surplus of the household is given by

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

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

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

[15] *'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.

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

The Nash bargaining criterion is given by

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

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

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

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

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

For comparison, if we would consider a model with a perfect labor market wage inequality is given by:[17]

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

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.

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

5 Equilibrium Solution and Calibration

From the households maximization problem given by eqns (12)-(16) lead to the following Euler equations[18]

$$
\begin{aligned}
\beta E_t\Big\{\frac{U_c(c_{t+1})}{U_c(c_t)}(1+r_{t+1}-\delta)\Big\} &= 1 && (27)\\
\beta E_t\Big\{-U_{h_s}(h_{s,t})+\lambda_{t+1}(w_{s,t+1}h_{s,t+1}+\kappa_s(s_{s,t+1}))+ & \\
\frac{\kappa_{h_s,s}(s_{s,t+1})}{p_{s,t+1}}\lambda_{t+1}(1-\psi_s-p_{h,t+1}s_{s,t+1})\Big\}-\frac{\kappa_{h_s,s}(s_{s,t})\lambda_t}{p_{s,t}} &= 0 && (28)\\
\beta E_t\Big\{-U_{h_u}(h_{u,t})+\lambda_{t+1}(w_{u,t+1}h_{u,t+1}+\kappa_u(s_{u,t+1}))+ & \\
\frac{\kappa_{h_u,u}(s_{u,t+1})}{p_{u,t+1}}\lambda_{t+1}(1-\psi_u-p_{u,t+1}s_{u,t+1})\Big\}-\frac{\kappa_{h_u,u}(s_{u,t})\lambda_t}{p_{u,t}} &= 0, && (29)
\end{aligned}
$$

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

$$
\begin{aligned}
f_k(\cdot)-r_t &= 0 && (30)\\
\frac{\lambda_t a_s}{\lambda_{t+1}q_{s,t}}-\beta E_t\Big\{f_{h_s}(\cdot)-w_{s,t+1}+\frac{a_s}{q_{s,t+1}}(1-\psi_s)\Big\} &= 0 && (31)\\
\frac{\lambda_t a_u}{\lambda_{t+1}q_{u,t}}-\beta E_t\Big\{f_{h_u}(\cdot)-w_{u,t+1}+\frac{a_u}{q_{u,t+1}}(1-\psi_u)\Big\} &= 0. && (32)
\end{aligned}
$$

An equilibrium of this economy is a set of variables

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

which 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

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

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

$$
\begin{aligned}
U(c_t,h_{s,t},h_{u,t}) &= \frac{c_t^{1-\Phi}}{1-\Phi}-\frac{h_{s,t}^{1-\nu_s}}{1-\nu_s}-\frac{h_{u,t}^{1-\nu_u}}{1-\nu_u} && (34)\\
\kappa_s(s_{s,t}) &= \bar{\kappa}_s s_{s,t}^{\mu} && (35)\\
\kappa_u(s_{u,t}) &= \bar{\kappa}_u s_{u,t}^{\mu}. && (36)
\end{aligned}
$$

[18] A detailed solution of the optimization problems can be obtained from the author upon request.

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

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

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

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

where we assume that the two skill-augmenting technology shocks, $\breve{z}_t, \tilde{z}_t$ 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. For the manufacturing sector of the German economy an overall quarterly job destruction rate of 3-4%. The destruction rates used for the calibration are chosen in accordance to this observation.

Furthermore, we assume, for simplicity, that the productivity shocks follow the same autoregressive process.

Table 5: Parameter Settings

$\bar{h}_s$	$\bar{h}_u$	$\bar{\bar{u}}_s$	$\bar{\bar{u}}_h$	$\bar{Z}$	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	-1.25	0.025
$\bar{\kappa}_u$	ψ_s	ψ_u	$\sigma_1(\sigma_2)$	ρ_1	ρ_2	a_h
$2\times\kappa_h$	0.02	0.06	0.3 (0.1)	0.7	0.7	$2\times a_u$
a_u	ϕ_h	ϕ_u	ε_h	ε_u	ω	ϵ_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[19]. The impulse response functions rely on a first order approximation of the stochastic model around its steady state.

6 Model Discussion

The first model we discuss in this section is a model without labor market frictions and also exhibits no wage bargaining.[20] In particular, the assumed model follows the DGE model by Lindquist (2004). However we assume a general 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). This shock could be interpreted as the introduction of a general purpose technology which increases the productivity of both kinds of workers, however at different magnitudes.

[19]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.

[20]A solution in detail of this model can be obtained from the author upon request.

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. However, the impact on skilled workers and the respective wages is higher than for low skilled workers. Due to the assumption of a skill bias we also observe an immediate increase in wage inequality. For employment and wage inequality we observe also a return to the steady state level after three to for years, since then the wage spread and the relative employment position become negative.

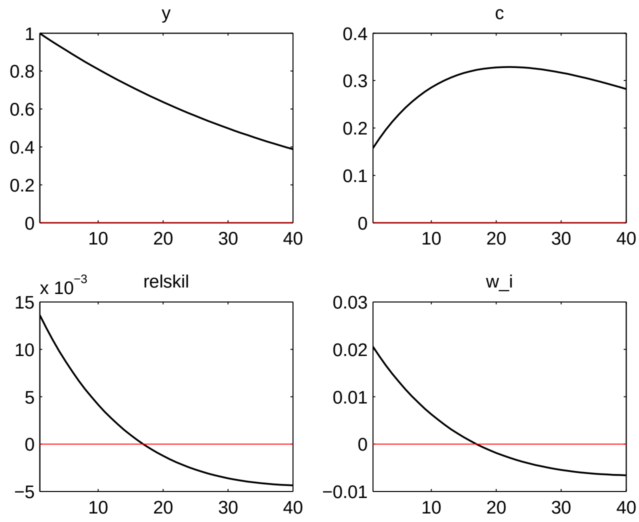

Figure 9: Introduction of a General Purpose Technology

In principle, the results match the empirical results of the U.S. wage spread (cf. figures 5 and 6), however the immediate response of the wage spread is not reproduced by the model.

In a next step (figures 10 and 11 below) we examine the question concerning the effects of the introduction of a technology which either augments the productivity of skilled or unskilled workers only.[21] There we observe an interesting result, that a single skill-augmenting technology shock leads to an increase in output and employment of both skill groups as well as in wage inequality.

In the opposite case (figure 11), we observe also positive responses of output and employment, however the response of inequality is negative. Furthermore, it is obvious that the responses of a shock which augments the productivity of low skilled workers is lower in magnitude than a shock which increases the productivity of high skilled workers.

[21] See e.g. Aghion (2002).

In general, the results are consistent with the empirical evidences concerning the assumption of skill-biased technical change. 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.

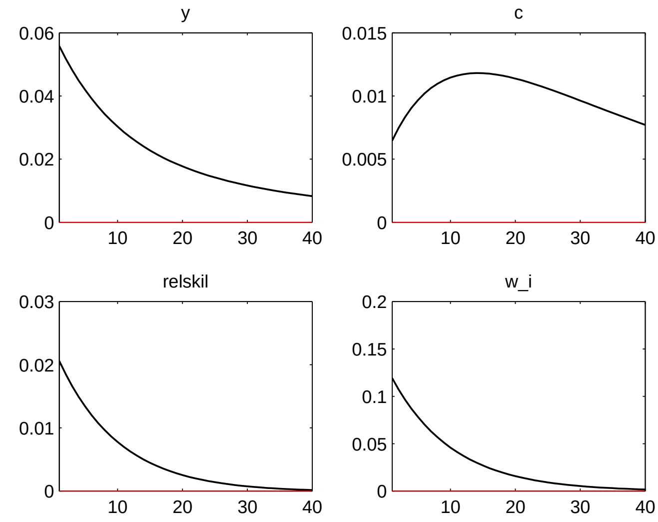

Figure 10: Model I, High-skill augmenting Technology

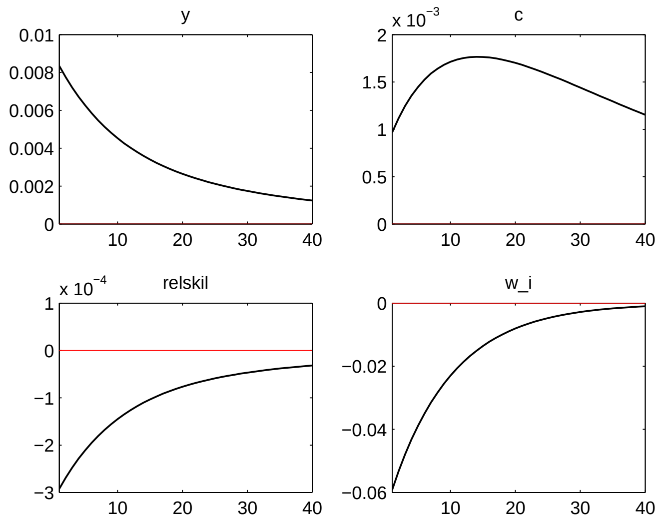

Figure 11: Model I, Low-skill augmenting Technology

In the second variant of our model we analyze the transmission of the introduction of new technologies under the assumption of labor market imperfections due to search and matching frictions. As in the preceding examination we analyze three different types of technology shocks.

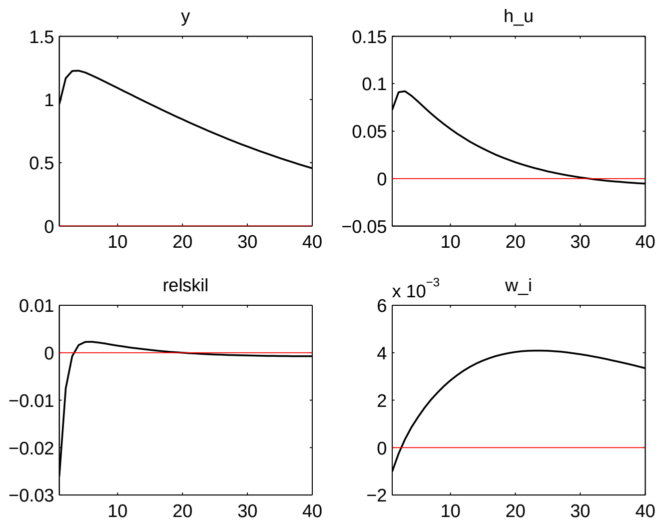

Figure 12: Model II, Introduction of a General Purpose Technology

Figure 12 above, presents the obtained responses to the introduction of a general purpose technology. In contrast to the assumption of perfect labor markets, the presented variables show a delayed response of a shock in technology. In particular, we observe a negative response of relative employment (also found in U.S. and German data), which is due to the fact of the greater availability and lower recruitment costs of low skilled workers. Furthermore, the response of the wage spread exhibits a hump shaped and rather persistent response which is found for the German economy (cf figure 7).

When the responses of skill augmenting technology shocks are studied we find similar results as for the model with perfect labor markets (see figures 13 and 14 below)

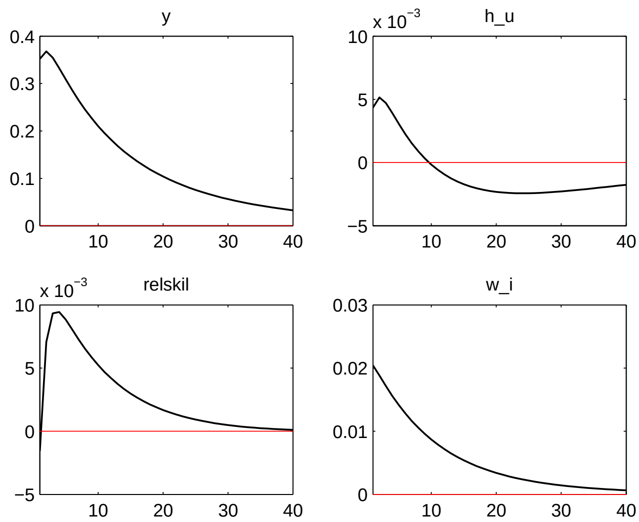

Figure 13: Model II, High-skill augmenting Technology

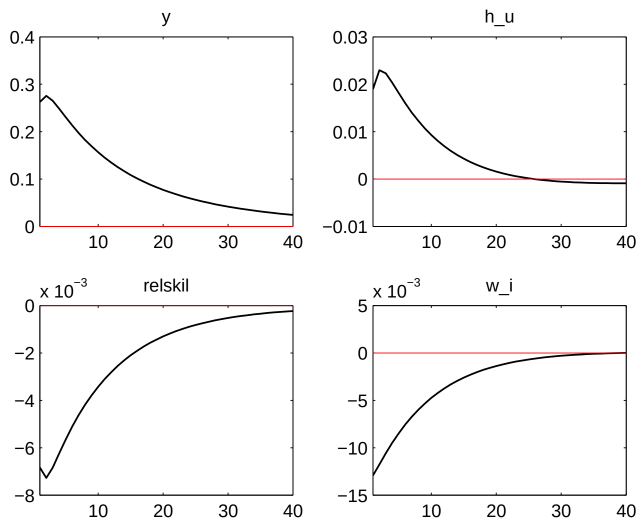

Figure 14: Model II, Low-skill augmenting Technology

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	z
					U.S., 1963.1-1998.4						
y	—	1.00	0.81	0.89	0.05	-0.01	0.12	0.37	0.33	-0.04	0.73
c	0.77		1.00	0.73	-0.01	-0.29	0.28	0.51	0.61	-0.27	0.67
i	2.44			1.00	0.02	-0.03	0.04	0.37	0.29	0.02	0.54
n_s	0.55				1.00	0.18	0.26	0.10	-0.11	0.27	-0.02
n_u	1.22					1.00	-0.90	-0.23	-0.48	0.40	-0.22
n_s/n_u	1.25						1.00	0.27	0.42	-0.27	0.21
w_s	0.95							1.00	0.71	0.15	0.41
w_u	1.16								1.00	-0.59	0.21
w_s/w_u	0.82									1.00	-0.20
z	0.68										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	0.54
c	1.47		1.00	0.62	-0.23	-0.19	0.10	0.27	0.18	0.09	0.24
i	2.24			1.00	-0.17	-0.13	0.06	0.33	0.33	-0.06	0.44
n_s	0.70				1.00	0.86	-0.45	-0.20	-0.11	-0.02	-0.09
n_u	1.16					1.00	-0.85	-0.23	-0.18	0.01	-0.06
n_s/n_u	0.67						1.00	0.20	0.17	-0.04	-0.16
w_s	0.22							1.00	0.76	0.27	0.48
w_u	0.24								1.00	-0.38	0.05
w_s/w_u	0.16									1.00	-0.37
z	0.61										1.00

(Correlation of observed Variables)

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 Model with Search Frictions

	relative Volatility	y	c	i	n_s	n_u	n_s/n_u	w_s	w_u	w_s/w_u	z
					Perfect Labor Markets (Correlation of simulated Variables)						
y	—	1.00	0.78	0.89	0.87	0.92	-0.01	0.95	0.96	-0.01	0.95
c	0.49		1.00	0.43	0.51	0.56	-0.08	0.87	0.89	-0.08	0.90
i	0.69			1.00	0.91	0.93	0.04	0.77	0.76	0.04	0.99
n_s	0.06				1.00	0.93	0.29	0.87	0.81	0.29	0.90
n_u	0.02					1.00	-0.06	0.77	0.76	-0.06	0.99
n_s/n_u	0.07						1.00	0.12	-0.82	1.00	0.02
w_s	0.08							1.00	0.98	0.12	0.83
w_u	0.07								1.00	-0.08	0.83
w_s/w_u	0.01									1.00	0.02
z	0.05										1.00
					Labor Market Frictions						
y	—	1.00	0.63	0.88	0.74	0.79	-0.05	0.99	0.99	0.30	1.00
c	0.49		1.00	0.18	-0.04	0.03	0.05	0.68	0.65	0.30	0.26
i	0.77			1.00	0.96	0.98	-0.06	0.83	0.85	0.19	0.97
n_s	0.05				1.00	0.95	0.07	0.71	0.69	0.28	0.89
n_u	0.05					1.00	-0.16	0.72	0.77	0.01	0.93
n_s/n_u	0.19						1.00	0.03	-0.13	0.63	-0.16
w_s	0.07							1.00	0.97	0.42	0.85
w_u	0.06								1.00	0.19	0.88
w_s/w_u	0.01									1.00	0.15
z	0.09										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 which is not found in the simulation 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.

All in all the ability of the models to reproduce some facts of the business cycle is mixed. The model with perfect labor markets generally overstates the correlation between variables whereas the second model version understates the variability.

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 (e.g. 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 generate 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.

References

Acemoglu, D. (1998). Why do New Technologies Complement Skills? Directed Technical Change and Wage Inequality. *The American Economic Review 113*(4), 1055–1089.

Acemoglu, D. (1999). Changes in Unemployment and Wage Inequality: An Alternative Theory and Some Evidence. *The American Economic Review 89*, 1259–78.

Acemoglu, D. (2002). Technical Change, Inequality and the Labor Market. *Journal of Economic Literature 40*, 7–72.

Aghion, P. (2002). Schumpeterian Growth Theory and the Dynamics of Income Inequality. *Econometrica 70*(3), 855–882.

Albrecht, J. and S. Vroman (2002). A Matching Model with Endogenous Skill Requirements. *International Economic Review 43*(1), 283–305.

Autor, D. H., L. F. Katz, and A. B. Krueger (1998). Computing Inequality: Have Computers Changed the Labor Market. *The Quarterly Journal of Economics 113*(4), 1169–1213.

Balakrishnan, R. and C. Michelacci (2001). Unemployment dynamics across OECD countries. *European Economic Review 45*, 135–165.

Bierhanzl, E. and J. Gwartney (1998). Regulation, Unions, and Labor Markets. *Regulation 23*(3), 40–53.

Blanchard, O. J. and P. A. Diamond (1989). The Beveridge Curve. *Brookings Papers on Economic Activity 1*, 1–76.

Blanchard, O. J. and J. Wolfers (2000). The Role of Shocks and Institutions in the Rise of European Unemployment: The Aggregate Evidence. *The Economic Journal 110*(1), C1–C33.

Cahuc, P. and A. Zylberberg (2004). *Labor Economics.* Cambridge, Mass.: The MIT Press.

Colecchia, A. and P. Schreyer (2001). ICT Investment and Growth in the 1990s: Is the U.S. a Unique Case? A Comparative Study of Nine OECD Countries. OECD STI Working Papers, No. 2001/7, Paris.

Dolado, J., F. Kramarz, S. Machin, A. Manning, D. Margolis, and C. Teulings (1996). The economic impact of minimum wages in Europe. *Economic Policy 12*(23), 319–357.

Fitzenberger, B. (1999). *Wages and Employment Across Skill Groups – An Analysis for West Germany.* Heidelberg: Physica Verlag.

Gautier, P. A. (2002). Unemployment and Search Externalities in a Model with Heterogenous Jobs and Workers. *Economica 69*, 21–40.

Gottschalk, P. and M. Hansen (2003). Is the Proportion of College Workers in Noncollege Jobs Increasing. *Journal of Labor Economics 21*(2), 449–471.

Greiner, A., J. Rubart, and W. Semmler (2004). Economic growth, skill-biased technical change and wage inequality: A model and estimations for the U.S. and Europe. *Journal of Macroeconomics 26*(4), 597–621.

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

Heckman, J. J. (2003). Flexibility and job creation: Lessons for germany. In P. Aghion, R. Frydman, J. Stiglitz, and M. Woodford (Eds.), *Knowledge, Information, and Expectations in Modern Macroeconomics*, Princeton, New Jersey, pp. 357–393. Princeton University Press.

Heckman, J. J., L. Lochner, and C. Taber (1998). Explaining Rising Wage Inequality: Explorations with a Dynamic General Equilibrium Model of Labor Earnings with Heterogeneous Agents. *Review of Economic Dynamics 1*, 1–58.

Hornstein, A., P. Krusell, and G. L. Violante (2005). The Replacement Problem in Frictional Economies: A Near-Equivalence Result. *Journal of the European Economic Association 3*(5), 1007–1057.

Juillard, M. (1996). DYNARE: A program for the resolution and simulation of dynamic models with forward variables through the use ofa relaxation algorithm. CEPREMAP Working Paper, No. 9602, Paris.

Katz, L. F. and D. Autor (1999). Changes in the wage structure and earnings inequality. In O. Ashenfelter and D. Card (Eds.), *Handbook of Labor Economics*, Volume III, Amsterdam, pp. 1463–1555. Elsevier Science B.V.

Katz, L. F. and K. M. Murphy (1992). Changes in Relative Wages 1963-1987: Supply and Demand Factors. *The Quarterly Journal of Economics 107*, 35–78.

Krätzig, M. (2004). The software jmulti. In H. Lütkepohl and M. Krätzig (Eds.), *Applied Time Series Econometrics*, Cambridge, New York, pp. 289–300. Cambridge University Press.

Krugman, P. (1994). Past and Prospective Causes of High Unemployment. (4), 23–43. Federal Reserve Bank of Kansas City Economic Review.

Krusell, P., L. E. Ohanian, V. Ríos-Rull, and G. L. Violante (2000). Capital Skill Complementary and Inequality: A Macroeconomic Analysis. *Econometrica 68*(5), 1029–1053.

Kydland, F. E. (1984). Labor-Force Heterogeneity and the Business Cycle. *Carnegie-Rochester Conference Series on Public Policy 21*, 173–208.

Lindquist, M. J. (2004). Capital-skill complementarity and inequality over the business cycle. *Review of Economic Dynamics 7*(3), 519–540.

Ljungqvist, L. and T. Sargent (1998). The European Unemployment Dilemma. *Journal of Political Economy 106*(3), 514–550.

Lütkepohl, H. (2004). Vector autoregressive and vector error correction models. In H. Lütkepohl and M. Krätzig (Eds.), *Applied Time Series Econometrics*, Cambridge, New York, pp. 86–158. Cambridge University Press.

Lütkepohl, H. and M. Krätzig (Eds.) (2004). *Applied Time Series Econometrics*. Cambridge, New York: Cambridge University Press.

Malinvaud, E. (1986). The Rise of Unemployment in France. In C. R. Bean, R. Layard, and S. J. Nickell (Eds.), *The Rise in Unemployment*, Oxford, New York, pp. 197–217. Basil Blackwell.

Merz, M. (1995). Search in the Labor Market and the Real Business Cycle. *Journal of Monetary Economics 36*, 269–300.

Mortensen, D. T. and C. A. Pissarides (1999). Unemployment Responses to 'Skill-Biased' Technology Shocks: The Role of Labour Market Policy. *The Economic Journal 109*, 242–265.

Murphy, K., W. Riddel, and P. Romer (1998). Wages, Skills and Technology in the United States and Canada. In E. Helpman (Ed.), *General Purpose Technologies and Economic Growth*, Cambridge, Mass., pp. 283–309. The MIT Press.

Nickell, S. and B. Bell (1996). Changes in the Distribution of Wages and Unemployment in OECD Countries. *American Economic Review Papers and Proceedings 86*(2), 302–308.

OECD (1989). *Employment Outlook 1989*. Paris: OECD Publications.

OECD (1993). *Employment Outlook 1993*. Paris: OECD Publications.

OECD (1996). *Employment Outlook 1996*. Paris: OECD Publications.

OECD (2003). *Education at a Glance 2003*. Paris: OECD Publications.

OECD (2004). *Employment Outlook 2004*. Paris: OECD Publications.

Petrongolo, B. and M. Manacorda (1999). Skill Mismatch and Unemployment in OECD Countries. *Economica 66*, 181–207.

Phelps, E. S. and G. Zoega (2001). Structural Booms. *Economic Policy 16*(32), 85–126.

Pierrard, O. and H. R. Sneessens (2003). Low-Skilled Unemployment, Biased Technological Shocks and Job Competition. IZA Discussion Paper, No. 784, Bonn, May.

Pissarides, C. A. (2000). *Equilibrium Unemployment Theory* (2nd ed.). Cambridge, Mass.: The MIT Press.

Rowthorn, R. (1999). Unemployment, wage bargaining and capital-labour substitution. *Cambridge Journal of Economics 23*, 413–524.

Saint-Paul, G. (1996). *Dual Labor Markets.* Cambridge, Mass.: The MIT Press.

Sims, C. A. (1980). Macroeconomics and Reality. *Econometrica 48*(1), 1–48.

Sims, C. A., J. H. Stock, and M. W. Watson (1990). Inference in Linear Time Series Models with Some Unit Roots. *Econometrica 58*, 113–144.

Yashiv, E. (2004). Macroeconomic Policy Lessons of Labor Market Frictions. *European Economic Review 48*, 259–284.

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 8: Testing for Unit Roots

	U.S., 1970.1-1998.4			Germany, 1973.1-2000.1		
Variable	Deterministic Terms	Lags	ADF Test Statistic	Deterministic Terms	Lags	ADF Test Statistic
w_s/w_u	constant, trend	2	-2.2512	constant, trend	2	-3.1488
$\Delta w_s/w_u$	constant	1	-4.8327	constant	1	-3.6900
n_s/n_u	constant, trend	2	-0.8772	constant, trend	2	-2.8551
$\Delta n_s/n_u$	constant	1	-6.9801	constant	1	-4.6459
Labor Prod.	constant, trend	2	-2.1758	constant, trend	2	-1.7099
ΔLP	constant	1	-5.3564	constant	1	-9.0036
v/u	constant, trend	2	-3.5116	constant,trend	2	-20.5764

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.[22]

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

Table 9: VAR Specifications

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

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