593 LECTURE NOTES IN ECONOMICS AND MATHEMATICAL SYSTEMS

Jens Rubart

The Employment Effects of Technological Change

Heterogenous Labor, Wage Inequality and Unemployment

Springer

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With 54 Figures and 21 Tables

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To my parents

Preface

The recent book has been prepared during my work as a research assistant at the Institute of Economics of the Darmstadt University of Technology, Germany. In July 2006 it was accepted as a Ph.D. thesis titled "Heterogeneous Labor, Wage Inequality and the Employment Effects of Technological Change – Theory and Empirical Evidence for the U.S. and Europe" at the Department of Law and Economics of the Darmstadt University of Technology.

In particular, I am indebted to my teachers Volker Caspari and Willi Semmler for giving me the advice and the opportunity to write this dissertation. My interest to work on the relationship between technological change and labor markets started during my studies at the University of Bielefeld where I participated in seminars on Economic Growth and Labor Markets held by Willi Semmler.

Early parts of this thesis and closely related research papers were presented at the ZEW Unemployment Workshop (Berlin, April 2001), the Zeuthen Workshop on Competition and Growth (Copenhagen, November 2001), the 7th Conference on Theories and Methods in Macroeconomics (Evry Val-d'Essone, June 2002), the 2003 Annual Meeting of the German Economic Association (Zürich, September 2003), the Economic Research Seminar at TU Darmstadt (June 2005), the Rhein-Main-Neckar Seminar on Labor Economics (Mannheim, November 2005), the 10th Conference on Theories and Methods in Macroeconomics (Toulouse, January 2006), the 12th International Conference on Computing in Economics and Finance (Limassol, June 2006), and the 2006 Annual Congress of the European Economic Association (Vienna, August 2006). It benefited from a variety of suggestions by, amongst others, Philippe Aghion, Ingo Barens, Pierre Cahuc,

Horst Entorf, Michael Krause, Franck Portier, Patrick Puhani, Günther Rehme and Reinhard Tietz.

Furthermore, I wish to thank my colleagues and friends Kristina Budimir, Rafael Gerke, Olaf Münster, Günther Rehme, Andreas Röthig, Hannes Spengler, and Niels-Peter Thomas for our common time in Darmstadt. Michael Dear, Philip Savage, and Andreas Röthig were very kind to proofread parts of this thesis.

I am particularly indebted to Rafael Gerke for our discussions and projects concerning Dynamic General Equilibrium models.

Oberursel, *Jens*
February 2007 *Rubart*

Contents

1

Introduction

[...] for while a capital is employed in this country it must create a demand for some labor; machinery cannot be worked without the assistance of men, it cannot be made but with the contribution of their labor
(D. Ricardo (1911))

1.1 Motivation

Through the centuries, the economic development of countries has been characterized by major technological revolutions, such as, for example, the introduction of the steam engine, electricity-based technologies, new production organizations such as the assembly lines devised by the Ford Motor Company, or the IT revolution in the 1990s.[1] In general, four important phases of economic development are considered: 1820-1913, 1913-1950, 1950-1973 and 1973 to the present, all characterized by the above-mentioned technological advances.[2] Meanwhile, it is evident that each shift in technology was followed by significant changes in the structure of employment. An interesting example of the effects of the steam engine for merchant shipping between 1865 and 1912 can be found in Chin, Juhn, and Thompson (2004). They show that the introduction of a new technology, the steam engine, created

[1] See, for example, Atkeson and Kehoe (2001) p. 6, or Landes (1999), ch. 18, for surveys of technological revolutions. Furthermore, the impact of the IT-Revolution is discussed in Greenwood and Yorukoglu (1997) and Gordon (2000).
[2] See Maddison (1991) p. 84 f.

a new demand for engineers whereby the demand for sailors declined. Furthermore, Chin, Juhn, and Thompson (2004) have found that the shift from sail to steam increased the 90/10 wage ratio[3] by 40%.

In general, the changes in wages and employment following a technological advance can be described as follows: some workers become obsolete, whereas those with a different skill set are needed for the production process. Due to the scarcity of workers with the required skill set the respective wages tend to increase. In recent times, since the mid-1990s IT revolution, economic researchers began to study the relationship between technological change and a heterogeneous labor force which differs in the skill set. This relationship has been the subject of a vast share of the recent economic literature and is subsumed under the concept of skill-biased technological change. In particular, the studies by Katz and Murphy (1992), Autor, Katz, and Krueger (1998), Goldin and Katz (1998, 1999), Katz and Autor (1999), and, in particular, Aghion, Caroli, and García-Peñalosa (1999) examined in detail the hypothesis of skill biased technological change.[4] The latter studies focus on the fact that in a period of major technological change the demand and wages for skilled workers increase. Although an increase in the supply of skilled workers should have led to a decline in the wages of skilled workers, induced technological advances lead to a further increase in demand for and wages of skilled workers (Acemoglu (1998)). A generally accepted indicator of skill biased technological change is

[3] Note that the 90/10 wage ratio describes the wage spread between the respective deciles of the wage distribution of an economy.

[4] It should be pointed out that the examination of "skill-biased technological change" is rather old. Examples of early studies that examine certain aspects of this hypothesis can be found in Reder (1955), Hansen (1961), or Tinbergen (1974).

the increasing gap between wages of skilled and unskilled workers during the last thirty years which is mainly observed in U.S. labor market data. Empirical evidence that support this technology-skill relationship include Fitzenberger (1999), Goldin and Katz (1999), Katz and Autor (1999), Card and DiNardo (2002), and Puhani (2005). Furthermore, in addition to the technology-skill relationship, the effect of capital-skill complementarity is also regarded as an explanation of the observed patterns of the wage spread and relative employment (see, for example, Skaksen and Sorensen (2005)). In particular, this approach lies in the focus of the work by Krusell, Ohanian, Ríos-Rull, and Violante (2000) and Lindquist (2004).

When surveying the existing literature on the technology-skill or the capital-skill bias, the literature is essentially subdivided into two main groups. The first group focuses on the long-run trend in inequality and relative employment. In general, this branch of the literature is built on endogenous growth models, such as Acemoglu (1998), Murphy, Riddel, and Romer (1998), Krusell, Ohanian, Ríos-Rull, and Violante (2000), Aghion (2002), and Greiner, Rubart, and Semmler (2004). However, as will be specified below, most of the theoretical studies do not examine labor market rigidities in detail, although empirical labor market studies point out the effects of labor market institutions. This second branch of literature focuses on the microeconomic evidence based on panel data studies as such as Fitzenberger (1999), Card and DiNardo (2002) and Puhani (2005). Furthermore, detailed empirical studies of the employment effects are presented by Layard, Jackman, Manacorda, and Petrongolo (1999) and Petrongolo and Manacorda (1999). However, most studies do not consider the time dimension of an technological advance, i.e. it requires some time until the introduction of a new technology leads to observable changes on the labor market. In particular, Nickell and Bell (1995) emphasize that a detailed analysis of the consequences of shocks on the relative employment status is missing, *[...] it is essential to understand the consequences for unemployment relativities of a neutral shock [...]* .[5] Furthermore, as pointed out by Nickell and Bell (1995, 1996), there are time periods in which unemployment tends to increase for both high and low skilled workers. However, this observation is not consistent with skill biased technological change as the only source of the high unemployment rates of low-skilled workers.

Subsequently, the work of Acemoglu (1999), Mortensen and Pissarides (1999), Albrecht and Vroman (2002), and Gautier (2002), lead the literature to focus on the labor market effects of technological change. Whereas the study by Acemoglu (1999) focuses on the long-term perspective, the latter studies tend to consider employment effects at business cycle frequencies. Furthermore, this branch of literature provides evidence for the hypothesis of dual labor markets raised by Saint-Paul (1996). The dualism-approach recognizes that a market can be characterized by two different states at the same time, for example different unemployment rates of workers with different characteristics. This characterization coincides with the observation of different unemployment rates of high- and low-skilled workers. Although the labor market is characterized as the most important market when looking at the transmission of supply and demand side shocks, the obvious dualism is not taken into account.[6]

[5] Cf. Nickell and Bell (1995) p. 43.

[6] For example, elaborate studies of the importance of the labor market frictions in order to investigate the effects of monetary policy shocks can be found in Walsh (2003) or Trigari (2004).

In recent times, many studies (see e.g. Ljungqvist and Sargent (1998)) attempt to explain the high and persistent unemployment rate of continental European countries. However, their analysis is almost based on partial equilibrium models which focus on the labor market, only. In general, they conclude that rigid labor market institutions or high taxes explain the observed unemployment pattern. However, the relationship between structural changes and labor market institutions from an aggregate perspective is not in the center of the discussion. In addition, partial equilibrium models do not consider the relations between different markets such as goods and labor markets.

The seminal work of Mortensen and Pissarides (1999) introduced the effect of skill biased technology shocks under the presence of labor market imperfections into the macroeconomic literature. However, from a general equilibrium point of view, the studies by Mortensen and Pissarides (1999) and Gautier (2002) seem to be more partial equilibrium models that mainly focus on the labor market rather than on the whole economy. First attempts to incorporate skill-biased technology shocks into a fully specified dynamic general equilibrium framework were made by Pierrard and Sneessens (2003, 2004) as well as Lindquist (2004); the latter study focuses on the effects of capital-skill complementarity and, furthermore, neglects labor market imperfections. In particular, the work of Pierrard and Sneessens (2003, 2004) provides a reasonable explanation of the unemployment pattern of low skilled workers in continental European countries because of the assumption of rigid relative wages.

Although the assumption that technological advances occur stochastically, such as by Lindquist (2004), might be questionable, this approach is the standard one referred to in the recent macroeconomic literature. In general, theoretical explanations of technological change or structural change as a source of fluctuations were developed by Juglar in 1856, who focussed on cycles of a length of between three and eighteen years. Cycles of a longer period were analyzed by Kondratieff, Kuznets, Schumpeter and many others during the first quarter of the 20th century.[7] Although many explanations, such as Schumpeter's creative destruction concept, seem reasonable, the assumption of the existence of regular periodical waves of economic activity is not proven. According to Maddison (1991) economic fluctuations are due mainly to disturbances of an *ad hoc* character (cf. Maddison (1991): 108). The recent business cycle theory is particularly built on the *ad hoc* character of technological disturbances, the "Real Business Cycle" (RBC) theory. Mainly developed by Kydland and Prescott (1982) and King, Plosser, and Rebelo (1988), it analyzes the effect of stochastic disturbances of aggregate productivity within a framework of a neoclassical growth model with intertemporal optimizing agents. In order to explain both output and employment fluctuations, the RBC approach was extended by Hansen (1985), as well as Christiano and Eichenbaum (1992). However, the latter expansions of the RBC framework did not account for labor market imperfections or institutional settings. This was done by Danthine and Donaldson (1990) who introduced efficiency wages and, in particular, by Langot (1995), Merz (1995) and Andolfatto (1996) who introduced search and matching frictions on the labor market into a RBC framework. Another line of research is offered by Gong and Semmler (2000) and Ernst, Gong, Semmler, and Bukeviciute (2006)

[7] See Maddison (1991), Chapter 4 for further details.

who study disequilibrium phenomena on the labor market within the context of a RBC model. In particular, the latter model concentrates on the impacts of structural reforms on the labor market. They show that an increase in labor market flexibility, i.e. a reduction of the impact of labor market institutions, improves economic welfare but leads to higher employment risk for households. However, the search and matching framework builds the basic framework of the recent macroeconomic literature which studies output and employment fluctuations.

Up to now, a characterization detailing under which conditions technological change leads to positive or employment effects, or how technological advances diffuse over the labor market is still absent. This is particularly relevant to whether labor market rigidities are taken into account, which are obviously prevalent in continental European labor markets (as opposed to the U.S.). Furthermore, it is still unclear how labor market policies, such as minimum wages or dismissal protection legislation, which have been recently discussed in Germany, affect the employment rate of low-skilled workers in an economy which is in a state of non-stop technological change. Therefore, the aim of this thesis is to provide a theoretical framework in which the effects of technological change can be studied and which is, moreover, capable of accounting for the main empirical findings of leading OECD countries.

1.2 Outline

This thesis is structured as follows. In Chapter 2 the main empirical findings concerning employment and wages of different educational groups as well as important labor market characteristics are presented and discussed. Furthermore, this chapter provides a reduced-form vector-autoregression (VAR) approach in which the effects of technological advances on the wage spread and the relative employment positions are studied empirically.

In chapter 3, the basic framework of search and matching frictions on the labor market is introduced. In addition, we discuss the effects of parameter variations by applying a calibration study to the obtained model solution which leads to a more detailed discussion of the effects of skill-biased technological change on employment and wage inequality, albeit within a rather static framework. There we can show that some of the cross-country variation in inequality can be reproduced by parameter variations of the model.

In chapter 4 the basic framework of a Stochastic Dynamic General Equilibrium (SDGE) model with heterogeneous labor is introduced and calibrated in accordance with empirical findings for the U.S. and Europe.

Subsequently, in chapters 5 and 6, the basic framework is extended by labor market frictions due to a search and matching approach as well as a wage-setting mechanism based on a Nash bargaining procedure. As in chapter 4, the model is calibrated in accordance with the empirical evidence. However, besides the search and matching frictions and wage bargaining, no other labor market institution or rigidity is assumed.

In Chapter 6 the search and matching approach is extended by two important labor market rigidities reported for continental European countries: rigid relative wages and employment protection mechanisms. In particular, the latter assumptions provide a theoretical and quantitative consideration of the outcomes of labor market policies. Furthermore, besides the dynamic response of technological innovations, long-run as well as welfare effects of both policies are examined.

Chapter 7 surveys the results and concludes with a final outlook.

1.3 A Preview of Results

A comparison of labor market characteristics of the important OECD countries (see table 2.1 below) makes it obvious that, at least in France and Germany, the high and increasing unemployment rates are mainly driven by the increase in unemployment rates for low-skilled workers. However, the respective unemployment rates tend to remain stable or decrease for countries like the U.S. and the United Kingdom. The recent empirical literature, based mainly on microeconometric panel studies (see, for example, Fitzenberger (1999) and Puhani (2005)), explains this pattern in the context of the effects of skill-biased technological change. However, due to the rather static examinations, the dynamic effects of advances in new technologies on relative employment and wages are not taken into account. By applying a reduced form VAR approach, these dynamic effects are examined empirically. There, we find evidence for the hypothesis of skill-biased technology shocks for the U.S. and Germany. Furthermore, it becomes obvious that labor market institutions have significant effects on the wage spread and relative employment. In particular, the latter results bag for a detailed discussion of the effects of technological advances under labor market rigidities.

Based on this evidence, a comparative static analysis of a labor market with search and matching frictions and wage bargaining is developed. There we show that it is generally possible to discuss the observed cross-country variation of wage inequality and relative employment within a single theoretical framework. In addition, we will show that the complex relationships between the variables of interest require numerical calibrations for a detailed elaboration. The results show that it is generally possible to reproduce the aggregate evidence of the observed wage spreads across important OECD countries within one model framework by parameter variations.

By conveying the comparative static analysis of chapter 3 into a Dynamic General Equilibrium framework, we are able to give a detailed examination of the dynamic effects of technological change under several kinds of labor market institutions. By comparing the results of models which exhibit an increasing degree of rigidity, we show how these effects worsen the employment position of low-skilled workers. In particular, when rigid relative wages are considered, an unanticipated shock of skill-biased technology leads to an immediate decrease in low-skilled employment. Furthermore, we show that policies which increase dismissal protection do not have an enormous impact on the employment position. In addition, the examination of the long-run effects of both labor market policies shows that wage rigidities reduce steady state employment of both types of workers as well as total welfare. However, we find no such effects for employment protection mechanisms.

2

The Empirics of Inequality and Institutions

On the other hand, students of income distribution are in need of more precise information on the possibilities of substitution between various categories of labour, since this influence the demand structure of the labour market
(J. Tinbergen (1974))

2.1 Technological Change and Economic Fluctuations

Early quantitative work on the structure of wages and employment in the United States began in the 1930s and focussed almost entirely on occupational and industry-specific wage differentials. The "human capital" revolution in the 1960s and 1970s as well as the availability of new data sets on earnings and individual characteristics forced a shift of focus to educational wage and employment differentials.[1]

A recent survey of the evolution employment and wage differentials across important OECD countries since 1980 is given below in table 2.1. In accordance with the literature, it is shown that, although many industrialized countries such as the United Kingdom,[2] the United States, France and Germany were faced with a similar evolution of technology and industrialization and that the percentage of college graduates increased in the last 30 years, which indicates an overall increase in employment of skilled workers; we observe, however, different patterns

[1] See Katz and Autor (1999) for a detailed survey of the literature.
[2] A recent study of the rise of the U.K. wage differential is given by Prasad (2002).

of wage inequality across countries. In general, Anglo-Saxon economies such as the U.S. or U.K. show a growing wage spread, whereas in continental European countries like France or Germany wage inequality tends to be constant (see also Gottschalk and Smeeding (1997) or Acemoglu (2002)). The constancy of the wage spread accounts, in line with the hypothesis of skill-biased technological change, for the increase in unemployment of low skilled workers which is obvious for continental European countries. As reported by table 2.1 below, in Germany the unemployment rate of workers with lower secondary education exhibits a steady increase from 13 to above 20% between 1988 and 2004. On the other hand, the unemployment rate of low skilled workers declined from 13 to 6% in the U.K. or remained constant in the U.S.. For comparison, the unemployment rate of skilled workers remained either at constant levels between 3 and 5%. However, it is interesting to notice that the participation rate of low skilled workers in continental European countries exceeds the one of Anglo-Saxon countries.

Table 2.1. 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	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	—	—
2004	10.3	12.1	7.6	6.2	76.6	86.5	91.3	—	—	—
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
2004	11.4	20.5	11.2	5.5	78.3	84.5	90.4	18.0	—	—
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	—	—
2004	4.7	6.6	3.7	2.2	56.8	82.4	89.6	—	—	—
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
2004	5.6	10.5	5.6	3.3	63.1	77.2	84.7	32.3	—	1.99

Sources: Greiner, Rubart, and Semmler (2004), Nickell and Bell (1996), OECD (1989, 1993, 1996, 2004, 2006), OECD (2003), 2006 Statistical Abstract of the U.S.

Before examining possible explanations of the evolution of the wage and employment structure, it has to be pointed out that each variable exhibits fluctuations at business cycle frequencies. A possible explanation of this observation is provided by Aghion (2002), who states that there is a shift in the capital-skill complementarity, meaning that technology or capital is either complementary to high-skilled or low-skilled workers. Particularly, the latter leads to a relative increase of wages of low skilled workers, which decreases the wage spread. Although this explanation accounts for long run shifts in the wage spread and the relative employment position, the observation that the variation in the data is at business cycle frequencies, is not explained. For Germany and the U.S. the findings are presented in figure 2.1 below.[3]

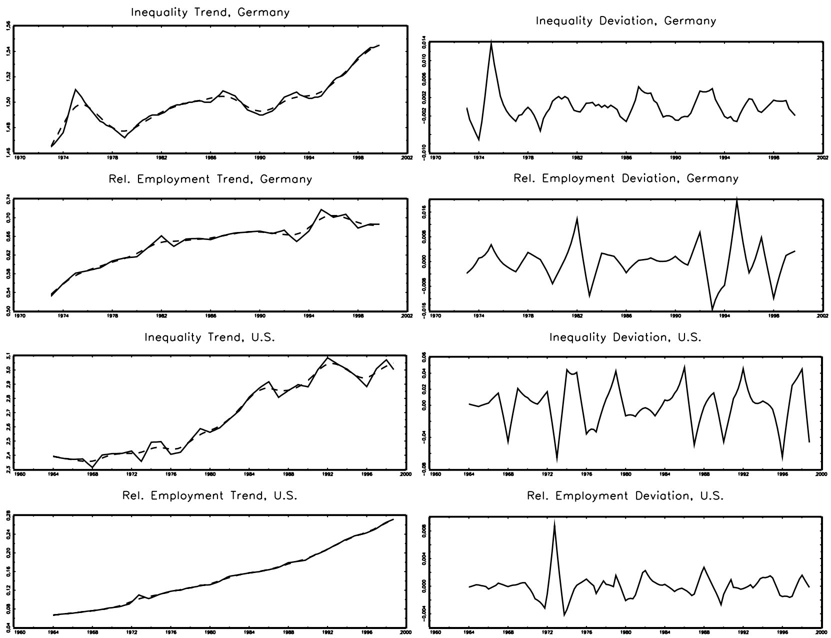

Fig. 2.1. Wage inequality and relative employment in the U.S. and Germany

[3] Note that the fluctuations of the data presented in figure 2.1 are measured in their deviation from the HP - Trend (dashed line, left column). The sources of the applied time series are described in appendix B.

For both countries we observe a steady increase in the wage spread and the relative employment position (figure 2.1, left column). Furthermore, it is obvious that each series fluctuates around the respective growth trend at business cycle frequencies (figure 2.1, right column). The mean annual growth rate of the German time series is reported as 0.191% (Std. dev.: 0.557);[4] for the U.S. we found an annual growth rate of 0.763% (Std. dev.: 2.014). Although the growth rate of wage inequality amounts to approximately one-third of the growth rate observed for the U.S., it proves to have a similar volatility when the standard deviation is considered relative to the respective national mean.

The observed pattern of the wage spread and the relative employment position are closely related to the hypothesis of "labor market dualism" raised by, for instance, Saint-Paul (1996), meaning that a market is characterized by two different states at the same time. This means, in the case of the labor market, that, in general, the labor markets of industrialized countries exhibit a pattern in which one group of workers is characterized by high earnings, low unemployment and low employment fluctuations, whereas a second group is faced with low wages, high unemployment and higher rates of fluctuations (Malinvaud (1986) p. 211).[5] An example of the dualism approach used to study the evolution of unemployment of skilled and unskilled workers is given by Saint-Paul (1996), in which he studies, amongst others, the influence of labor market institutions such as employment protection mechanisms

[4] Please note that the considered time series differs from the data published by the OECD. However, the slight positive growth rate is in line with findings of Fitzenberger (1999). See also Greiner, Rubart, and Semmler (2004) for an application of this time series.

[5] The theory of dual labor markets was developed in the United States in the 1970s in the context of debates on poverty and discrimination. See Saint-Paul (1996) p. 2.

due to firing costs.[6] Figures 2.2 and 2.3 show the different behavior of unemployment rates of different skill groups in recent times.[7] There, it is obvious that the unemployment rate of college-educated workers shows a significant lower volatility compared to the unemployment of less educated workers. In addition, this observation holds for the U.S. and Germany.

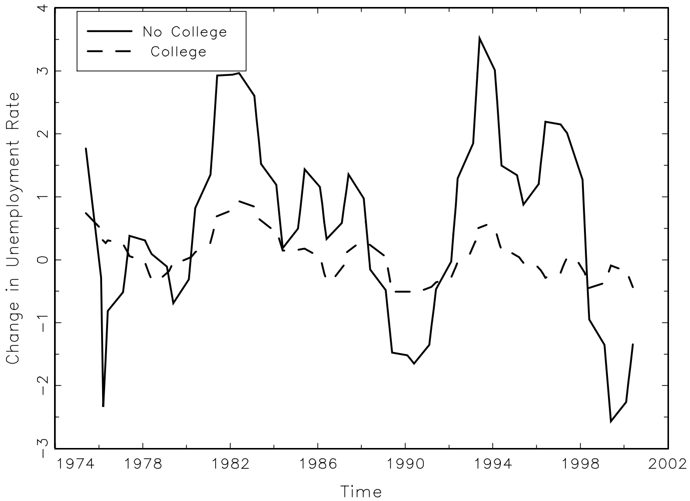

Fig. 2.2. Skill specific unemployment rates, Germany, 1975.4-2004.4

[6] See Saint-Paul (1996), chapter 9. The importance of firing costs is also analyzed by Bentolila and Bertola (1990), Delacroix (2003).

[7] For Germany the data are taken from the Institut für Arbeitsmarkt und Berufsforschung. The U.S. data are taken from the U.S. Bureau of labor statistics. See also appendix B for further details.

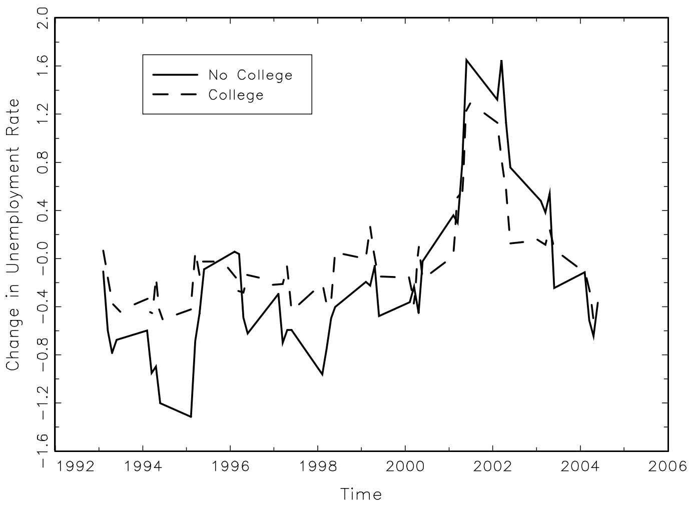

Fig. 2.3. Skill specific unemployment rates, U.S., 1993.1-2004.4

From a theoretical point of view, one could argue that this pattern is devoted to a higher increase in the number of skilled workers which dampened their respective marginal products. However, this pattern is explained by the different evolution of labor market institutions, particularly due to different wage-setting mechanisms. For example, Acemoglu, Aghion, and Violante (2001) explain this pattern with a significant decrease in the impact of trade unions in Anglo-Saxon countries. However, the amount of workers engaged in trade unions decreased in most of the OECD countries during the last 20 years (table 2.3 below), whereas the degree of centralized wage-setting as well as the amount of social benefits remained rather high in France and Germany compared to the U.S. and the U.K. (see table 2.4). Furthermore, when the evolution of wages and employment of different skill groups is considered, one observes significant fluctuations in the data. Beside the general relationship between wage inequality and the observed dualism at the labor market, as outlined above, a further determinant should be considered. In principle, it is outlined by Phelps and Zoega (2001), who state that the observed path of unemployment and economic performance is subject to, for instance, non-monetary shocks and developments, mainly due to investment activities of firms. In particular, investment activities determine the evolution of physical capital which is in a complementary relationship to skilled and unskilled labor. A comparison of the investment ratio (total investment per GDP) of leading OECD countries shows a significant decline in this ratio for continental European countries such as France and Germany, in contrast to steady increases for the U.S. and the U.K. (see table 2.2 below). During the same time period we observe a constant or increasing unemployment rate for France and Germany and low or decreasing ones for the U.S. and the U.K. (cf. table 2.1 above). However, although there is a general decline in the investment ratio in France and Germany, an increasing amount of investment is devoted to information and communication technologies. This means that, although general indicators of the economic activity decline, the structural change due to investments in new technologies seems to be unbroken.[8]

[8] ICT investments are measured as percentage of non-residential investment of the whole economy (Cf. Colecchia and Schreyer (2001)).

Table 2.2. Total and ICT investment

Year	U.S.	U.K.	Germany	France
	Total Investment to GDP, %			
1970-80	15.2	15.5	28.8	24.1
1980-90	16.2	13.9	21.0	19.5
1990-00	17.3	15.1	21.2	19.5
2004	19.8	16.3	18.4	20.2
	ICT Investment			
1980	15.2	4.8	12.2	6.8
1990	22.5	10.1	13.9	12.7
1995	26.1	15.6	13.3	13.3
2000	39.9	15.0	16.2	16.2

Sources: Colecchia and Schreyer (2001), OECD Main Economic Indicators 2005.

2.2 The Empirics of Labor Market Institutions

The importance of institutional labor market rigidities when analyzing continental European labor markets is particularly highlighted by Nickell (1997), Blanchard and Wolfers (2000) or Heckman (2003) who refer to the rigidity of the labor market of continental European countries as the major cause of the high unemployment and the low economic performance.[9] However, one should correct the statements concerning the high unemployment rates, because we observe high unemployment rates particularly for low-skilled workers. The unemployment rate of skilled workers is nearly the same across main OECD (see table 2.1).

[9] A further explanation is given by Blanchard and Giavazzi (2003) who state that high product market rigidities also account for the low economic performance. However, product and labor market rigidities are so strongly correlated that the impact of each source is very difficult to determine.

The importance of market frictions can be explained by outward shifts of the Beveridge curve which relates the unemployment rate to the vacancy rate of an economy. In general, we expect a downward sloping curve which states that high unemployment rates coincide with with low vacancy rates and vice versa. An outward shift of this curve indicates the existence of mismatch and structural problems on the labor market, for example, that an unemployed worker is not good for the job, i.e. the worker's education does not fulfill the employer's requirements. Figures 2.4 and 2.5 show the Beveridge-curve relationship for the U.S. and Germany.[10]

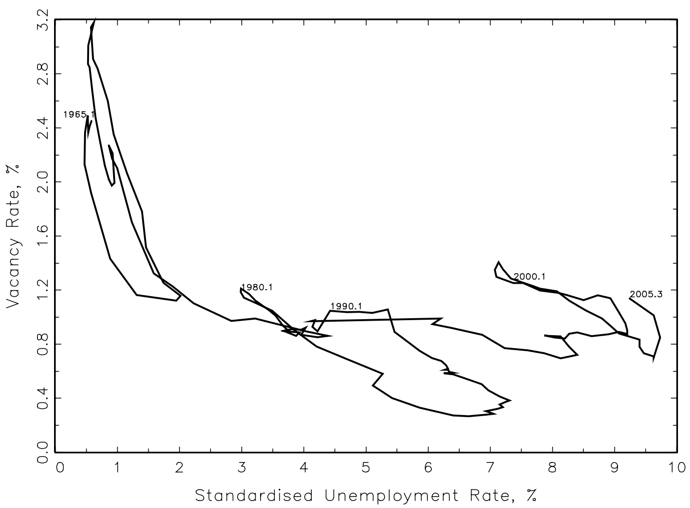

Fig. 2.4. Beveridge curve, Germany, 1965.1-2005.3

[10] The data are taken from the OECD Main Economic Indicators 2006.

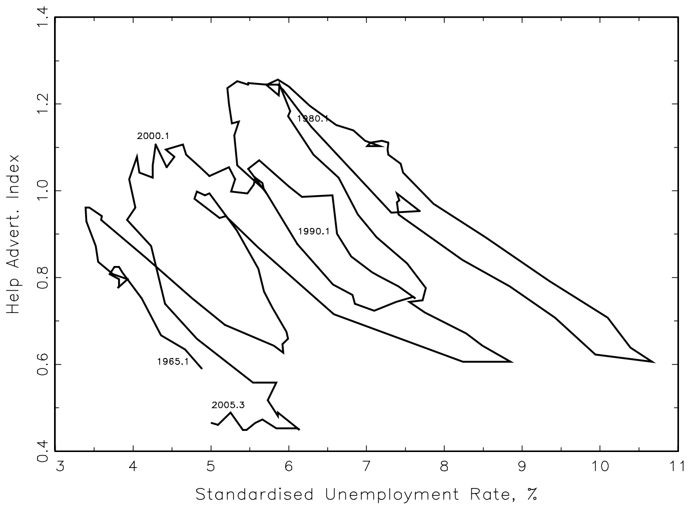

Fig. 2.5. Beveridge curve, U.S., 1965.1-2005.3

Whereas the Beveridge curve remains rather stable for the U.S. a significant shift to the right is observed for the German economy (figure 2.4). In general, there are two explanations for this behavior, skill mismatch, i.e. the unemployed worker is mismatched with the job requirements, and to rigid labor market institutions which raise the worker's reservation wage above the wage he would be employed at, as is shown by Blanchard and Wolfers (2000) or Heckman (2003).

As already mentioned, labor markets are characterized by various kinds of institutions. In general, these institutions determine the behavior of key outcomes of this particular market, for example the transition rates in and out of employment, the evolution of long term unemployment, and, in particular, the wage-setting procedures.[11]

According to Nickell et al. (2003) labor market institutions are treated in general as: unemployment benefits, trade unions (union density), labor taxes, all kinds of wage inflexibility, and employment protection mechanisms. Institutions such as unemployment benefits or labor taxes are determinants of labor costs, however, employment protection mechanisms encompass any regulations that limits the employers ability to dismiss the worker without delay or a cost. In general, the OECD distinguishes between five types of employment protection mechanisms:[12]

1. Administrative procedures,
2. Notice of termination,
3. Severance payments,
4. Difficulty of dismissal,
5. Additional measures for collective dismissal, for example costs or inconveniences whether the dismissal exceeds a prescribed number of employees.

As we will analyze in more detail in chapters 6.1 and 6.3, a general approach to model employment protection mechanisms is to assume firing costs. In accordance to the characterization described above, firing costs can be treated as a general difficulty (cost) of dismissal that enters the firm's decision problem when hiring or dismissing a worker. Furthermore, the question if firing costs affect the wage distribution or

[11] See, for instance, Nickell (1997), and Blanchard and Wolfers (2000) for studies concerning the role of labor market institutions in the rise in European unemployment.

[12] See Pissarides (2001) p. 136.

the observed increase in unemployment rates of low-skilled workers is still open.

An important factor which has a significant impact on the wage distribution is, as shown by Blau and Kahn (2001), the existence of minimum wages.[13] Although the existence of minimum wages is very important, there is a lack of time series data for this variable.

In order to give a comparable overview of labor market institutions across important OECD countries we focus particularly on three main indicators: union density, bargaining coverage and benefit replacement rates. The impact of trade union power is examined to a greater degree, because trade unions have an enormous impact on U.S. and German wage setting, and have a completely different structure in each country. Table 2.3 below presents an overview of the above mentioned labor market institutions by comparing index numbers of employment protection, trade union density, the bargaining coverage, benefit payments, as well as minimum wages. There, it can be seen that the high bargaining coverage as well as high benefit payments, which also determine minimum wages, imply more inflexible wage setting regimes in continental Europe than in anglo-saxon countries.

[13] See Dolado et al. (1996), Blau and Kahn (1999), and Lee (1999) or Gosling and Lemieux (2001) for detailed discussions of the impact of minimum wages on explaining the wage distribution.

Table 2.3. A collection of labor market institutions

Year	U.S.	U.K.	Germany	France	U.S.	U.K.	Germany	France
	Employment Protection				Union density			
1980	0.10	0.35	1.65	1.30	0.23	0.56	0.35	0.19
1995	0.10	0.35	1.41	1.50	0.15	0.37	0.29	0.10
2001	—	—	—	—	0.12	0.31	0.24	0.10
	Bargaining Coverage				Benefit Replacement Rates			
1980	0.26	0.70	0.91	0.85	0.34	0.33	0.39	0.62
1995	0.18	0.47	0.92	0.95	0.27	0.22	0.36	0.58
2001	0.14 (2000)	> 0.30 (2000)	0.68 (2000)	> 0.90 (2000)	0.19	0.17	0.32	0.50
	Minimum Wages							
1993	0.39	0.40	0.55 (1991)	0.50				
1997	0.39	0.43	0.60	0.71				
2004	0.42	0.40	< 0.60	0.47				

Sources: Nickell, Nunziata, Ochel, and Quintini (2003), Bierhanzl and Gwartney (1998), Dolado et al. (1996), OECD (1997), European Foundation for the Improvement of Living and Working Conditions (EIRO), Brandt, Burniaux, and Duval (2005), 2006 Statistical Abstract of the U.S. and own calculations

Although union density has decreased over time for each country, the number of employees covered by collective wage bargaining varies in its pattern (see table 2.3 above). In particular, for Germany and France we observe the highest level of bargaining coverage and also an increase in this measure. On the other hand, for the U.S. and U.K. this rate has decreased. Similar results are found for a measure of employment protection mechanisms. It becomes obvious that in 1995 the measure of employment protection for France and Germany exceeds the one for the U.S. and the U.K. at least at factor four. Because of the close relation between unemployment benefits and reservation wages, which measure a possible minimum wage, minimum wages in France or Germany are significantly higher than in Anglo-Saxon economies. As can also be seen from table 2.3 benefit replacement rates and, furthermore, payments from the social security system are important factors in wage setting, particularly in continental European countries. In particular, such payments determine reservation wages. Table 2.4 compares the unemployment insurance payments of the above-mentioned OECD countries.

Table 2.4. Unemployment benefits

	Unemployment Insurance			*Unemployment Assistance*	
	Payment	Max. benefit[a] in USD (yearly)	Duration (months)	Max. benefit in USD (yearly)	Duration (months)
Germany[b]	60%	30,890	12	27,286	no limit
Germany[c]	30% (min.)	21,600	no limit	–	–
France	75%	60,184	60	4.479	no limit
U.K.	Flat Rate	4,084	6	4.084	no limit
U.S.	50%	15,600	6	–	–

Source: OECD (2002) and own calculations

[a] Payments in per cent of gross earnings, except Germany (net earnings). 1999 purchasing power parity units are used by the OECD to calculate the USD values.
[b] Note that the German data describe the benefit payments before the so-called Hartz IV reform.
[c] Please note that the results shown in this table give only a very rough description and do not include all possibilities of payments which are offered by the new unemployment benefit system in Germany which started in January 2005. A more detailed survey can be found, for example, in Sachverständigenrat (2004), p. 229 f.

Table 2.4 shows that the most generous social security benefits are paid in European OECD countries. In particular, France grants the highest payments during the first 60 months after closing one's job. After the termination of unemployment insurance payments, all countries, except Germany, pay significantly lower unemployment assistance benefits. Without loss of generality, we can state that, compared to the U.S. and U.K., France and Germany show the highest degree of labor market institutions and, furthermore, the strongest relationship between institutions and wage setting.

Beside the effects of institutions on wage-setting mechanisms, a further determinant of labor market rigidity is employment protection legislation. In line with theoretical arguments, the relative employment ratio should show a positive correlation with employment protection mechanisms. By relating an employment protection index to the growth of the relative employment ratio, we obtain the following figure for important OECD countries:

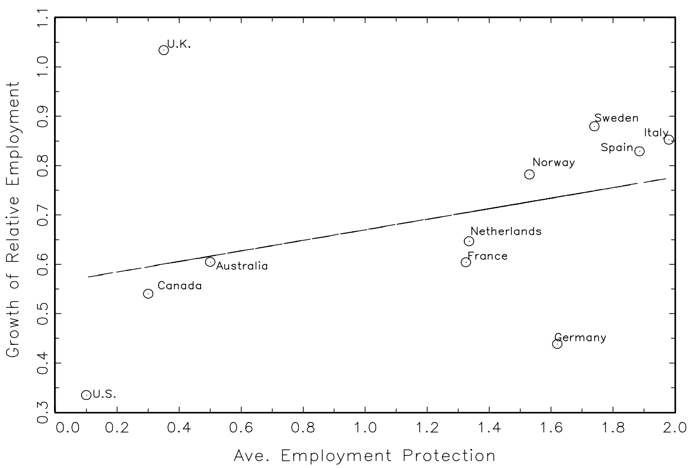

Fig. 2.6. Employment protection and relative employment

For any considered country, a significant increase in the relative employment position of skilled workers is reported by figure 2.6.[14] However, as suggested by the positive slope of the regression line, which states that higher employment protection goes at hand with an increase in the relative employment position of skilled workers.

A similar result is found for the relation between the level of minimum wages and the unemployment rate of low-skilled workers.

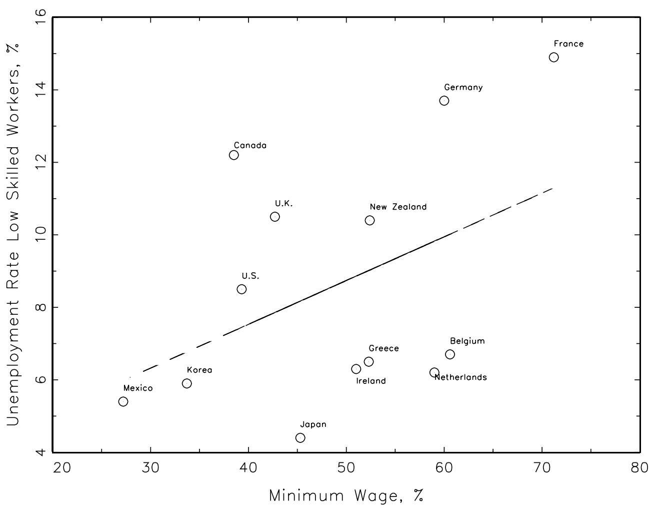

Fig. 2.7. Minimum wages and low skilled unemployment

As shown by figure 2.7 above, in OECD countries a higher level of minimum wages is positively correlated with a higher rate of low-skilled

[14] The data on relative employment are taken from Layard, Jackman, Manacorda, and Petrongolo (1999) for the years 1980 and 1989. The growth rate is calculated as $x_{1989}/x_{1980} - 1$. The employment protection index is taken from the labor market institutions database by Nickell, Nunziata, Ochel, and Quintini (2003), the data applied in the regression are the arithmetic means of the variables in 1980 and 1989. The solid line is calculated by OLS : *constant* : 0.56(4.54), β : 0.106(1.15), $R^2 = 0.09$, t-statistics in parentheses.

unemployment.[15] Although, the empirical relation is rather weak, the data show that for main continental European countries like France and Germany, a high level of minimum wages coincides with high rates of low skilled unemployment. Furthermore, although the minimum wages decreased in Germany and France during the last couple of years the rate of low skilled unemployment remained at rather high levels (cf. table 2.1).

2.3 Empirical Analysis

2.3.1 Empirical Methodology

The collection of stylized facts of the preceding sections highlight significant differences in the evolution of labor market institutions as well as in earnings and employment differentials. In addition, the relevance of wage-setting institutions in a non-homogeneous labor market, particularly in the case of Germany, is shown by Fitzenberger (1999). However, the empirical studies on wage inequality and labor market institutions are generally examined in a static framework, although the underlying theory is a dynamic one.[16] Furthermore, the results of Nickell and Bell (1995, 1996) hamper a more elaborate examination from a dynamic point of view.

[15] The data for minimum wages and unemployment are taken from the OECD (1997) as well as OECD (2000). Furthermore, the data set is enlarged by data taken from EIRO publication "Minimum Wages in Europe", available at `www.eiro.eurofund.eu.int`. The data are collected for the year 1997, except for Germany and Ireland where the data represent the years 2003 and 2004, respectively. Furthermore, the unemployment rate of low skilled workers is defined in accordance to the OECD, i.e. it measures unemployed workers who earned less than a secondary educational degree. The solid line of figure 2.7 is calculated by OLS: $constant : 2.703(0.72)$, $\beta : 0.1207(1.64)$, $R^2 = 0.12$, t-statistics in parentheses.

[16] *[...] it could be fruitful to formulate the model as a dynamic bargaining model [...]*, cf. Fitzenberger (1999) p. 202.

The focus of this section is on raising the question of whether there is a relationship between main variables of interest, i.e. wage inequality, the employment status of different skill groups, and labor market institutions, which can be identified empirically in a dynamic framework. To be consistent with the theory discussed in the following chapters and to ensure comparability between countries, the empirical analysis concentrates on aggregate data only.

A reasonable approach analyzing the questions above is to specify and estimate a vector autoregression (VAR) model.[17] Based on this empirical model, one is in a position to compute impulse-response functions which show the dynamic effects of an orthogonal (uncorrelated) innovation in one variable on other variables of interest. Furthermore, the derived impulse response functions allow the evaluation of the outcomes of the theoretical models which are discussed in the following chapters.

In general, the VAR methodology postulates that all variables in the system are endogenous and can be written as a linear function of its own lagged values and the lagged values of all other variables in the system. Let y_t a vector of k time series whose dependency can be characterized by k linear equations; we can then express this relationship by the following structural VAR (SVAR) representation

$$B_0 y_t = c + B_1 y_{t-1} + ... + B_p y_{t-p} + u_t, \qquad (2.1)$$

where B_i represents a quadratic matrix of autoregressive coefficients and c gives a $(k \times 1)$ vector of constants. Furthermore, u_t denotes a $(k \times 1)$ vector of white noise structural disturbances with the properties

[17] A detailed description of the VAR methodology can be found in Lütkepohl (1993) or Hamilton (1994), chaps. 10 and 11.

of a zero mean and a time-invariant variance-covariance matrix. If both sides of (2.1) are premultiplied by B_0^{-1} the result is a VAR model which can be viewed as the reduced form of the general dynamic structural model (2.1):[18]

$$y_t = A_0 + A_1 y_{t-1} + ... + A_p y_{t-p} + \varepsilon_t, \tag{2.2}$$

where

$$A_0 = B^{-1}c \tag{2.3}$$

$$A_i = B^{-1}B_i, \qquad \text{for} \quad i = 1, 2, ...p \tag{2.4}$$

$$\varepsilon_t = B^{-1}u_t, \tag{2.5}$$

where ε_t is a vector of white noise disturbances with the properties

$$E(\varepsilon_t) = 0 \tag{2.6}$$

$$E(\varepsilon_t \varepsilon_\tau') = \begin{cases} \Sigma_\varepsilon & \text{for} \quad t = \tau \\ 0 & \text{otherwise.} \end{cases} \tag{2.7}$$

where Σ_ε denotes a $(k \times k)$ positive definite matrix. In comparison to the structural VAR representation (2.1), consistent estimates of the coefficients of A_i can be obtained by OLS; in addition the matrix Σ_ε can be calculated from the regression residuals.

As with any covariance-stationary process, a VAR can be represented as a vector moving average (VMA),[19] i.e. the variables $y_{k,t}$ can be expressed in terms of the current and past values of the respective shocks $\varepsilon_{k,t}$. This characteristic can be used in order to obtain impulse-response functions, i.e. a representation that describes the response of $y_{k,t+s}$ to a single impulse in $y_{k,t}$, a methodology which was introduced

[18] Cf. Hamilton (1994) p. 327.
[19] See, for example Hamilton (1994) p. 259 ff.

by Sims (1980). In particular, we are interested in so called orthogonalized impulse response functions, that are obtained when the innovations of the original VAR, ε_t, are decomposed into a set of uncorrelated components, $\tilde{\varepsilon}_t$, which are used to compute the consequences for y_{t+s} of a unit impulse in $\tilde{\varepsilon}_{j,t}$. The decomposition of the residuals is, as mentioned above, based on the VMA representation of the VAR process, as given by (2.2), i.e.

$$y_t = \sum_{s=0}^{\infty} \tilde{\Theta}_s \tilde{\varepsilon}_{t-s}, \tag{2.8}$$

where the elements of the matrix $\tilde{\Theta}_s$ denote the consequence of a one-unit increase in the j-th variable at date t for the value of the i-th variable at date $t+s$, $\partial y_{t+s}/\partial \tilde{\varepsilon}'_t = \tilde{\Theta}_s$.[20] Furthermore, where the components of $\tilde{\varepsilon}_t = (\tilde{\varepsilon}_{1,t}, ..., \tilde{\varepsilon}_{k,t})'$ are uncorrelated and have a unit variance, i.e. $\Sigma_{\tilde{\varepsilon}} = I_K$, where I_K denotes a $(k \times k)$ identity matrix.

In particularly, the parameters of interest are the dynamic multipliers. These coefficients can be obtained from the moving average coefficients ($\tilde{\Theta}_s$) and a Cholesky decomposition of the variance-covariance matrix Σ_ε. A Cholesky decomposition is obtained if a diagonal matrix D whose diagonal components are the variance of $\varepsilon_{j,t}$ is defined, which leads to the following representation of the standard errors of $\varepsilon_{j,t}$ in the form of a diagonal matrix $D^{\frac{1}{2}}$. This leads to the following decomposition of the variance-covariance matrix [21]

$$\Sigma_\varepsilon = AD^{\frac{1}{2}}D^{\frac{1}{2}}A' = PP', \tag{2.9}$$

[20] Cf. Hamilton (1994) p. 318.

[21] Cf. Hamilton (1994) p. 322. Note further that if the matrix of structural parameters $B_0 =$ (cf. equation (2.1)) is exactly equal to the matrix A^{-1}, then the orthogonalized innovations would coincide with the structural disturbances, i.e.

$$u_t = B_0 \varepsilon_t = A^{-1} \varepsilon_t,$$

(Hamilton (1994) p. 328.).

where

$$P \equiv AD^{\frac{1}{2}}.$$

In this representation a change of one component of ε_t has no effect on other components because the components are orthogonal, i.e. uncorrelated. Because the component's variances are one, an innovation with the amount of one is an innovation of the size of one standard deviation. Then the elements of the matrix $\tilde{\Theta}_s$ represent the effects of a innovation of the $k-th$ variable on variable i.

2.3.2 Estimation Results

The relation of interest in this section[22] 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, Riddel, and Romer (1998) as well as Greiner, Rubart, and Semmler (2004) and assuming a CES production technology, this relation can be written as follows:

$$w^{\text{spread}} = \frac{w_t^s}{w_t^u} = \frac{\gamma}{1-\gamma} \cdot {X_t}^{\xi_s - \xi_u} \left(\frac{n_{s,t}}{n_{u,t}} \right)^{-\frac{1}{\sigma}}, \tag{2.10}$$

where γ denotes the income share of each type of labor, X_t gives the level of technology, ξ_s, ξ_u define 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 (2.10) in logarithms, a linear representation of the wage spread is obtained:

$$\hat{w}^{\text{sp}} = \hat{\beta}_0 + (\xi_h - \xi_u)\hat{x}_t - \frac{1}{\sigma}\hat{n}_t, \tag{2.11}$$

[22] This section mainly refers to Rubart (2006).

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 (2.11), are at the center of many empirical examinations, for example by Katz and Murphy (1992), Katz and Autor (1999), or Krusell, Ohanian, Ríos-Rull, and Violante (2000).

In order to derive a dynamic framework, equation (2.11) will be rewritten as a VAR representation, which will be specified and estimated with 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 (2.11) reads as follows

$$\begin{pmatrix} \hat{w}^{\mathrm{sp}} \\ \hat{n}_t \\ \hat{x}_t \\ \hat{\theta} \end{pmatrix} = A_0 + \sum_{i=1}^{p} A_i \begin{pmatrix} \hat{w}^{\mathrm{sp}}_{t-i} \\ \hat{n}_{t-i} \\ \hat{x}_{t-i} \\ \hat{\theta}_{t-i} \end{pmatrix} \begin{pmatrix} \epsilon_{w,t} \\ \epsilon_{n,t} \\ \epsilon_{x,t} \\ \epsilon_{\theta,t} \end{pmatrix}, \tag{2.12}$$

where A_0 denotes a $j \times 1$ vector of intercept terms and A_i, for $i = 1, ..., p$, $j \times j$ are matrices of coefficients of endogenous lagged variables. Note that j equals the number of assumed variables.

The general approach to measure technological advances over the business is to calculate what is known as the Solow residual. For example, Ernst, Gong, and Semmler (2006)) refer to this measure in order to estimate the parameters of a business cycle model with non-clearing labor markets. However, the calculation of this residual, which is generally based on a growth accounting exercise, requires consistent measures and availability of time series of the capital stock. To avoid such problems technological change is measured by the index of labor productivity which is, as shown in appendix C, closely related to the TFP measure (TFP = Total Factor Productivity). In this thesis 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.[23] In addition, the above VAR is extended by market tightness, i.e. the vacancy-unemployment ratio.[24] Although this ratio does not measure the influence of labor market institutions directly, it is an important variable for determining the bargaining power during negotiation procedures, and it also captures structural imbalances. The results of table 2.5 indicate non-stationary behavior of the time series in levels, whereas unit roots are not found when first differences are taken into account. For the 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, Stock, and Watson (1990) and specify and estimate VAR (see equation (2.12)) models in levels in order to account further for long-run relationships between the considered variables. This approach further ensures that most of the available information included in the data is used in the estimation.[25] After the consideration the time se-

[23] 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 B.

[24] 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.

[25] See also Enders (1995) p. 301 for a discussion of estimating VAR models in levels.

ries properties of the applied time series the the lag length of the VAR models for the U.S. and German economies are determined by using the general information criteria (see table 2.6, below).[26]

Table 2.5. Testing for unit roots

	U.S., 1972.1-1998.4			Germany, 1975.1-2000.1		
Variable	Deterministic Terms	Lags	ADF Test Statistic	Deterministic Terms	Lags	ADF 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
GDP	constant, trend	2	-2.6987	constant, trend	2	-1.5955
ΔGDP	constant	1	-5.4999	constant	1	-7.2240
I/GDP	constant, trend	2	-1.7021	constant, trend	2	-1.6720
$\Delta I/GDP$	constant, trend	1	-5.2501	constant	1	-8.7411
TFP	constant, trend	2	-2.5671	constant, trend	2	-2.3649
ΔTFP	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

[26] A detailed description of the specification tests can be found in Lütkepohl (1993) or Lütkepohl (2004) p. 110 f.
All estimations as well as the obtained impulse-response functions are computed using JMulTi, available at `www.jmulti.de`, based on Krätzig (2004).

Table 2.6. VAR specifications

Information criteria	Variables (intercept and linear time trend included)							
	U.S., 1972.1-1998.4				Germany, 1975.1-2000.1			
	w_s/w_u n_s/n_u GDP	w_s/w_u n_s/n_u I/GDP	w_s/w_u n_s/n_u LP	w_s/w_u n_s/n_u LP θ	w_s/w_u n_s/n_u GDP	w_s/w_u n_s/n_u I/GDP	w_s/w_u n_s/n_u LP	w_s/w_u n_s/n_u LP θ
AIC	10	2	10	10	6	2	2	10
FPE	10	2	10	10	6	2	2	6
HQ	2	2	2	2	2	2	2	6
SC	2	2	2	2	2	2	2	2

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

For the subsequent estimations of the VAR models as specified above, a general lag length of two is chosen which is supported by the Hennan&Quinn (HQ) as well as the Schwarz criterion (SC). After estimating the respective models, the innovations of each VAR are orthogonalized by a Cholesky decomposition of the variance-covariance matrix. As outlined in the previous subsection, this representation, according to Sims (1980), allows us to calculate impulse-response functions.

According to Acemoglu (1998) an increase in the relative supply of skilled workers should decrease the wage premium in the short run, whereas technological change-induced inventive activities increase the demand for skilled workers in the long run and, therefore, lead to an increase of the wage premium.[27] In general, irrespective whether the hypothesis of skill-biased technological change, as outlined by Acemoglu (1998), is valid, we should observe a negative response of the wage

[27] Cf. Acemoglu (1998) p. 1057.

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. In taking the v/u ratio as an exogenous indicator of the labor market position, we 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 for both types of workers of finding a job. Because of the greater availability of unemployed low-skilled workers, an increase in the latter ratio should lead to a higher increase in low-skilled employment relative to the employment of skilled workers.

The obtained regression results for the equations of the wage spread and relative employment are shown in tables 2.7 and 2.8 below. As we will show below, significant evidences of the skill-biased technological change hypothesis is found for the U.S. in the time period between 1978 and 1998. Therefore, we reduce the considered time interval for the U.S. from 1972 to 1978.[28]

[28] Please note that significant results (at least at the 10% level) of tables 2.7 and 2.8 are written in bold letters.

Table 2.7. Estimation results, U.S. 1978.1-1998.4

Variable	Deterministic Terms	Endogenous lagged Variables			
	const.	$w_s/w_u(t-1)$	$n_s/n_u(t-1)$	$X(t-1)$	$v/u(t-1)$
w_s/w_u	-0.2202	**1.7242**	-0.0736	0.0612	-0.0064
	(0.7234)	(22.0183)	(-0.7343)	(0.7039)	(0.9334)
		$t-2$			
		-0.7765	0.0659	**-0.0032**	0.0032
		(-9.6051)	(0.6728)	(-0.0363)	(0.5940)
n_s/n_u	**-0.6444**	**-0.1072**	**1.7647**	**0.2510**	**-0.0150**
	(-2.8488)	(-1.8421)	(23.7102)	(3.8831)	(-3.1834)
		$t-2$			
		0.0594	**-0.7999**	-0.1091	**0.0110**
		(-0.9888)	(-10.9932)	(-1.6431)	(2.7214)

t-statistics in parentheses.
Significance: 10%: 1.658; 5%: 1.980 (cf. Mood, Graybill, and Boes (1974) p. 556.)

For the U.S., the results presented in table 2.7 initially show a significant negative intercept term of the equation of relative employment. However, the impacts of technology and wages are in accordance with the theoretical explanation. In particular, an increase in technological advances leads to a significant increase in relative employment, i.e. in the employment of skilled workers. In the short run, an increase in the v-u-ratio leads in the first period to a decline in the relative employment ratio, however, this effect changes significantly if longer time periods are taken into account. 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 2.8, below). As in for the U.S. data, the intercept term for the relative employment ratio turned out to be significant for the German data, too. Furthermore, the relationships between inequality and relative employment mostly behave similarly for both economies. However, advances in technology and the labor market status have insignificant but decreasing effects on the relative employment ratio. These results might be explained by the German educational system which is characterized by vocational training activities of the firms. Because of this "training-on-the-job" rather low-skilled workers are enabled to work in skilled-workers jobs, which leads to a decline in the relative employment ratio.

Table 2.8. Estimation results, Germany 1975.1-2000.1

Variable	Deterministic Terms	Endogenous lagged Variables			
	const.	$w_s/w_u(t-1)$	$n_s/n_u(t-1)$	$X(t-1)$	$v/u(t-1)$
w_s/w_u	-0.0117	**1.7752**	0.0084	0.0108	-0.0004
	(-1.0383)	(27.7772)	(0.5077)	(1.0213)	(-0.7793)
			$t-2$		
		-0.76969	-0.0103	-0.0052	0.0006
		(-11.6969)	(-0.6294)	(-0.5856)	(1.1227)
n_s/n_u	**-0.1530**	-0.0084	**1.6259**	-0.0114	-0.0012
	(-3.3666)	(-0.0325)	(24.1989)	(-0.2662)	(-0.5422)
			$t-2$		
		-0.0855	**-0.7058**	0.0462	-0.0007
		(-0.3104)	(-10.6739)	(1.0747)	(-0.3293)

t-statistics in parentheses.
Significance: 10%: 1.658; 5%: 1.980 (cf. Mood, Graybill, and Boes (1974) p. 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. Please note that changes in the order of variables do not lead to significant differences in the obtained impulse-response functions. Figures 2.8 and 2.9 below show the responses of an innovation in technology calculated for a 10-year period for the U.S. economy.[29]

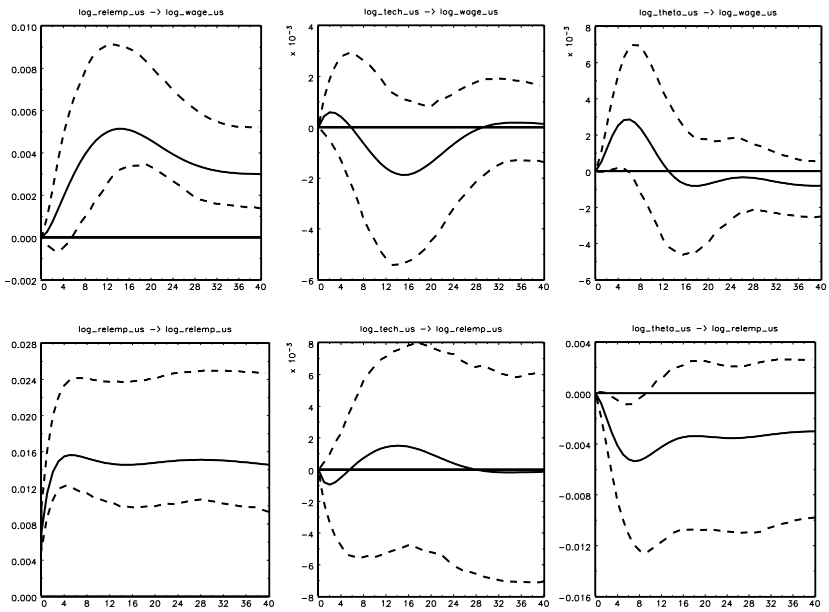

Fig. 2.8. Impulse-response functions, U.S. 1972.1 - 1998.4

[29] 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). Furthermore, a change in the order of variables of the estimated VARs does not lead to significant differences in the obtained impulse responses.

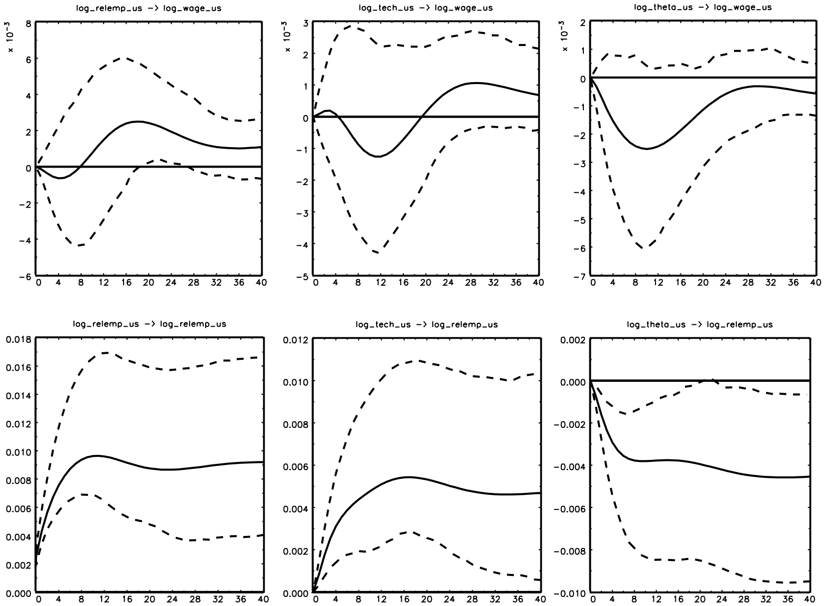

Fig. 2.9. Impulse-response functions, U.S. 1978.1 - 1998.4

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 which, however, turns negative afterwards (figures 2.8 and 2.9, up left). For the time period between 1972.1 and 1998.4 we observe only a small increase in relative employment after a technology shock (2.8, second row, middle). However, for the period between 1978.1 and 1998.4 an increase in technology leads to a significant increase in relative employment. The impact of technology on the wage spread is rather low for both time intervals, at least for the second period we observe a small increase in wage inequality after six years. An innovation in the labor market tightness, θ has in both cases dampening effects on the wage spread. However, we find a significant and persistent reduction in relative employment which indicates that an increase (decrease) in vacancies (unemployment) favors the employment position of low skilled workers. 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 "supply effect" of an increase in the supply of skilled workers is reproduced by the empirical results.

For Germany, the results of the VAR are shown by figure 2.10 below.

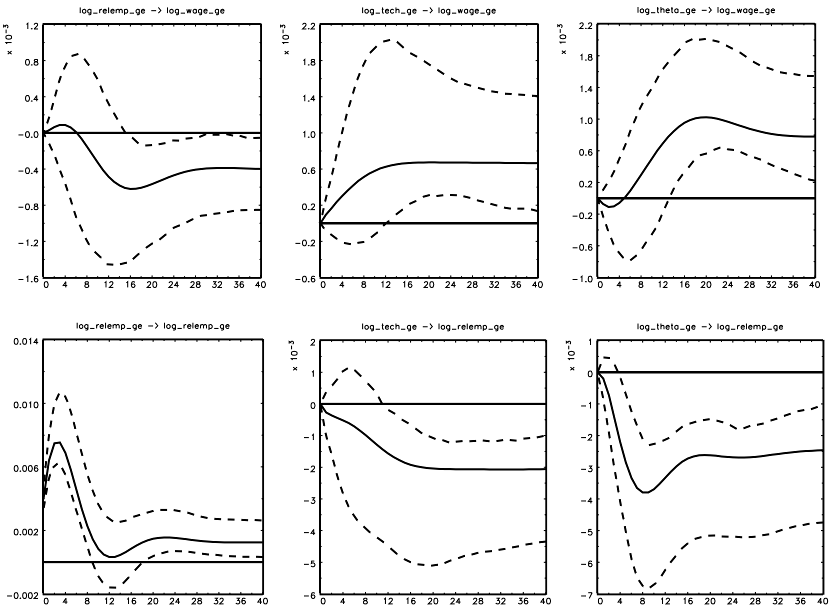

Fig. 2.10. Impulse-response functions, Germany 1973.1 - 2000.1

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 2.10, up left) as well as a positive response of the wage spread to an increase in technology. 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. However, the same innovation leads to a reduction in the relative employment position of skilled workers (figure 2.10). The latter effect might be due to the fact that in Germany, in contrast to the U.S., a successful institution of vocational education exists which enables workers without college education to work in jobs which require higher qualifications.

As shown by the empirical analysis, wage inequality and relative employment behave differently in response to advances in technology in the U.S. and Germany. In the U.S., technology shocks lead to rather instantaneous improvements in employment, whereas in Germany we observe reactions in wages (and the wage spread) rather 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 rather than in higher employment. Therefore, it seems questionable whether a DGE framework with perfect labor markets, as assumed by Lindquist (2004), for instance, is able to account for the empirical observation.

2.4 Discussion

The recent chapter presented a collection of key stylized facts concerning the evolution of educationally-based wage inequality and the employment status of different skill groups for important OECD countries. It showed, in line with the literature, e.g. Saint-Paul (1996), that the wage spread exhibits significant fluctuations at business cycle frequencies. Furthermore, a fact which holds for every considered country is that the fluctuation in unemployment (employment) is significantly higher for lower-skilled workers. The same finding holds for the respective unemployment rates of low-skilled workers. However, when table 2.1 is considered, the unemployment rate of low-skilled workers remained rather stable or even declines for anglo-saxon countries whereas for Germany a significant increase in the respective unemployment rate is observed.

Beside the problem of the skill mismatch, which should lead, given similar technological advances in both countries, to a similar pattern of unemployment in the U.S. and Europe, the different institutional arrangements are considered as the main source of the rise in central European unemployment, especially of low skilled workers.[30] As described by tables 2.3 and 2.4, main differences are collective bargaining systems as well as more generous social or unemployment benefits.

Besides the rather descriptive part of this chapter, a more sophisticated approach was undertaken in order to obtain more detailed insights into the dynamic relationships between variables. A rather simple VAR model was built and estimated with several indicators of economic activity and technological change. With this VAR the main hypothesis of the theory of skill-biased technological change was evaluated. As described by Acemoglu (1998), an increase in the relative supply of skilled labor should lead to a short-run decrease in the wage spread and, induced by technological advances, to an increase in the wage spread in the longer run. However, whether this dynamic effect can be found in the data was still an open question. The results of the estimated VARs and the derived impulse-response functions have shown that this hypothesis holds. In particular, it was shown that the response wage

[30] See, e.g. Blanchard and Wolfers (2000) for a survey of the impact of labor market institutions on continental European unemployment. Furthermore, the recent study by Ljungqvist and Sargent (2005) refers to layoff costs and generous unemployment compensation as the source of high unemployment rates in Europe.

spread and the relative employment variables exhibit a significant delayed pattern due to advances in technology and an increase in the relative supply of skilled workers.

Although the VARs studied in the recent chapter cannot compete with elaborate microeconometric studies based on panel data, the results gave several suggestions for a dynamic theory which will be developed in the subsequent chapters. The key suggestions are that the response of relative employment and inequality exhibit a delayed or hump-shaped structure; in addition, irrespective of whether a significant relation exists, relative employment displays a persistent reaction to advances in technology.

3

Technological Change, the Labor Market, and Wage Inequality

The third question is whether the increased 'dualism' prevailing in the French labour market induced a rise of frictional unemployment [...] unemployment increases much more slowly for highly qualified labour than for ordinary wage-earners.
(E. Malinvaud (1986))

3.1 Introduction

As outlined in the previous chapter, significant differences in the educational wage spread as well as in the relative employment position are observed across important OECD countries. Possible sources of the observed differences are widely discussed in the empirical and theoretical literature (see for example Aghion, Caroli, and García-Peñalosa (1999), or Katz and Autor (1999) for detailed surveys). However, there is a gap between empirical and theoretical evidences on wage inequality and employment. For example, Fitzenberger (1999), and Puhani (2005) give empirical evidence of the relationship between labor market institutions and relative employment and wage inequality. However, most of the theoretical work assumes perfect labor markets and derives the wage spread as the ratio of the marginal products of skilled and low skilled workers. Labor market institutions, such as trade unions and wage bargaining schemes are mostly not considered. In addition, the question remains as to whether it is possible to explain the observed cross-country differences within one theoretical framework when labor market institutions are considered. For example, Greiner, Rubart, and Semmler (2004) estimate an endogenous growth model with skill-biased technological change for the U.S. and Germany and show how different parameters of the underlying model are able to account for U.S.-German differences in wage inequality. Nevertheless, the above study did not account for country-specific labor markets or even labor market institutions.

A recent approach that seeks to bridge the gap between theoretical and empirical studies was introduced by Acemoglu, Aghion, and Violante (2001), who enter search unemployment and wage bargaining into a model of endogenous growth. Further approaches can be found in Mortensen and Pissarides (1999) and Petrongolo and Manacorda (1999) who also apply a search and matching framework. However, the latter studies concentrate either on the effects of skill-biased technology shocks or mismatch problems in the labor market and do not consider the behavior of other macroeconomic variables such as output, consumption and investment.

In order to outline fundamental relationships between technological change, labor market institutions and the resulting wage and employment pattern, model framework that includes labor market frictions and wage bargaining is developed in this chapter. Due to the assumption of search and matching frictions, the recent approach follows the work of Mortensen and Pissarides (1999). Of course, the characterization of the labor market and the determination of unemployment due to search and matching frictions may not give a satisfactory explanation of any type of unemployment, however, this approach offers a general formulation of labor demand and supply behavior of the respective agents, i.e. firms and households, and also it allows for the determination of an equilibrium unemployment rate. The main idea behind the assumption of search and matching frictions is that the price mechanism is not the only allocative mechanism, i.e. it is assumed that trade between the suppliers and applicants of vacant jobs is a costly and time-consuming process.[1] In addition, this approach enables us to consider two important labor market institutions, wage bargaining schemes and social security systems. In particular, the latter institution is an important determinant of reservation wages. The framework described above is used to discuss the effects of technological change on the employment status and wages of different educational groups. Furthermore, besides an analytical examination, the model is calibrated in accordance with empirical evidences for the U.S. and Germany.

The remainder of this chapter is organized as follows, section 3.2 outlines the general theoretical framework in order to discuss the relationship between technological change, wage inequality under the assumption of labor market imperfections. In section 3.3 the model is calibrated in accordance to empirical evidences for the U.S. and Germany, and in section 3.4 the results are discussed.

3.2 Theoretical Framework

In the model framework described below we distinguish between firms and households. Each firm uses skilled and unskilled labor inputs to

[1] An introductory survey of search and matching models in Cahuc and Zylberberg (2004), whereas the most detailed one can be found in the book by Pissarides (2000).

produce a single output good. For simplicity, in this chapter we do not consider capital accumulation and capital-labor substitution.[2]

The representative household consists of a continuum of skilled (n_s) and unskilled (n_u) workers. Both types of workers can either can be employed or unemployed, i.e. $n_i = h_i + u_i$, where h_i (u_i) describes the fraction of (un)employed workers of type $i = s, u$. If a worker is unemployed, he searches for a new job in order to become employed in the next period. For simplicity, it is assumed that no learning (or schooling) activities take place and that the labor market activities of both types of agents are separated from each other, i.e. high-skilled workers only apply for high-skilled jobs and low-skilled workers can only apply for low-skilled jobs.[3] Within a long-run perspective, the assumption that skilled workers are allowed to apply for low-skilled jobs still holds. However, this assumption appears unnecessary if short or medium-run effects of technological advances are considered. Furthermore, the assumption of separated labor markets is supported empirically by Gottschalk and Hansen (2003).

For the subsequent analysis the following definitions are needed:

$\Omega_{i,t}^{H}$: Value of an employed worker of type $i = s, u$

$\bar{\Omega}_{i,t}^{H}$: Value of an unemployed worker of type $i = s, u$

$\Omega_{i,t}^{F}$: Value of a filled job position of type $i = s, u$

$\bar{\Omega}_{i,t}^{F}$: Value of an open job vacancy of type $i = s, u$.

[2] Please note that this assumption is dropped in the following chapters.

[3] Two recent studies by Gautier (2002) and Pierrard and Sneessens (2003) extend this assumption and allow high-skilled workers to apply for low-skilled jobs. As we will show in chapters 5 and 6 below, the assumption of separated labor markets does not stand in the way of the replication of the results of Pierrard and Sneessens (2003).

Given the assumption concerning the production technology, in which the output good is produced with both types of workers, the value of a low and a high skilled job is also determined by the availability of both types of workers and the level of technology, z. By contrast, the value of an unemployed worker only depends on the respective benefits and individual value of being non-employed.

If both firms and workers, meet a match will be formed, i.e. a firm that offers a vacant job gets the job filled if the following condition holds

$$\Omega_t^F(i) + \Omega_t^H(i) \geq \bar{\Omega}_t^H(i) + \bar{\Omega}_t^F(i).$$

The above condition states that the aggregate surplus of both a firm and the member of the household has to exceed the value of the respective outside option, i.e. the sum of the value of remaining unemployed and the value of an open job vacancy.

The firm's value of a filled job of type i is determined as the worker's marginal product net wage payments as well as the weighted discounted values of an unfilled vacancy $\psi_i \bar{\Omega}_i^F$ and the value of a filled vacancy $(1-\psi_i)\Omega_i^F$. More explicit

$$\Omega_i^F = f_{h_i}(z, h_s, h_u) - w_i + \beta\big(\psi_i \bar{\Omega}_i^F + (1-\psi_i)\Omega_i^F\big), \qquad (3.1)$$

where $f'(\cdot)$ denotes the marginal productivity of a type i worker and w_i the respective wage rate. The parameter ψ_i gives the probability a productive job becomes unproductive in the next period. In this notation, the job creation process is formulated as an investment process under uncertainty where, for example, Ω_i^F denotes the expected present value of the revenues produced by a type-i worker with respect to the constraint that a job remains productive with probability $(1-\psi_i)$. In addition, even if the job does not become productive, the firm still receives the value from holding the position vacant.[4] The value of a vacant position is given by

$$\bar{\Omega}_i^F = -\kappa_i(v_i) + \beta\big(q(\theta_i)\Omega_i^F + (1 - q(\theta_i))\bar{\Omega}_i^F\big), \tag{3.2}$$

where $\kappa_i(v_i)$ denotes the costs of creating a job vacancy (v_i) and $q_i(\theta_i)$ gives the probability an unfilled job becomes productive. Furthermore, the parameter β denotes the discount factor, i.e. $\beta = \frac{1}{1+r}$, with r as the interest rate.

From the household's perspective, the value of a job, i.e. of an employed worker, follows as

$$\Omega_i^H = w_i + \beta\big(\psi_i\bar{\Omega}_i^H + (1 - \psi_i)\Omega_i^H\big); \tag{3.3}$$

and the value of an unemployed worker follows analogous

$$\bar{\Omega}_i^H = b_i + \beta\big(\theta_i q_i(\theta_i)\Omega_i^H + (1 - \theta_i q_i(\theta_i))\bar{\Omega}_i^H\big), \tag{3.4}$$

where b_i denotes social security or unemployment benefit payments and θ_i indicates the market tightness, i.e. the vacancy-unemployment ratio, at the type i labor market.

Because of the zero profit condition of vacant jobs[5], i.e. $\bar{\Omega}_i^F = 0$, the following value of a filled job can be derived from (3.2)

$$\begin{aligned} \kappa_i(v_i) &= \beta q(\theta_i)\Omega_i^F \\ \Omega_i^F &= \frac{(1+r)\kappa_i(v_i)}{q_i(\theta_i)}. \end{aligned} \tag{3.5}$$

[4] As in the literature, the above described decision processes are discussed by solving the respective Bellman equations. A detailed discussion of investment processes under uncertainty by using the Bellman equation can be found, for example, in Dixit and Pindyck (1994), p. 95 f.

[5] The zero-profit conditions follows from the fact that in equilibrium firms exploit all profit opportunities from creating new jobs, which drives the respective rents to zero (cf. Pissarides (2000) p. 11).

A job is created if the marginal product of labor is at least equal to the wage rate plus the expected capitalized value of the firm's hiring costs (cf. Pissarides (2000): 12). In order to obtain the job creation condition of the firm it is referred to equation (3.5) which is used to rewrite (3.1) to

$$\Omega_i^F = f_{h_i}(z, h_s, h_u) - w_i + (1 - \beta(1 - \psi_i))\frac{1+r}{q_i(\theta_i)}\kappa_i(v_i) \geq 0 \tag{3.6}$$

Equation (3.6) states that a job is created whether the marginal product of a worker exceeds the wage rate as well as the present value of an open vacancy in the next period.

In order to close the model, we have to define the labor market flows as well as the wage setting procedure. Unemployment of a type i worker evolves as

$$u_{i,t+1} = \psi_i h_{i,t} - M_{i,t}(u_i, v_i), \tag{3.7}$$

and by referring to the following definition[6]

$$\theta_i q_i(\theta_i) = M_i(u_i, v_i),$$

equation (3.7) can be rearranged and solved for the equilibrium unemployment rate which depends on the exogenous rate of job destruction, ψ_i, and the tightness of the labor market, θ_i and the probability a vacant job becomes productive,

$$u_i = \frac{\psi_i}{\psi_i + \theta_i q_i(\theta_i)}. \tag{3.8}$$

In accordance with the literature (e.g. Pissarides (2000), or Cahuc and Zylberberg (2004)) it is assumed that wages are the outcome of

[6] Note that this relationship is determined by the assumption that the matching function is linear homogeneous; then the probability a vacant job becomes filled in the next period is given by: $M_i(\cdot)/v_i = q_i(\theta_i) = M(\frac{u_i}{v_i}, 1)$. A detailed survey of the matching function can be found, for example, in Petrongolo and Pissarides (2001).

a bargaining process between workers and firms. Within this process both sides look for an agreement on how to share the outcome of the activity in which they are jointly involved. In general, such behavior can be observed in central European labor markets where a high degree of centralized wage bargaining is observed. The resulting share one party receives depends on that party's bargaining power as well as the outside option.

Under the assumption that the worker or its respective monopoly union bargains with the firm over wages only, and the firms decides over its labor demand alone. Let ϕ_i denote the bargaining power of the union; the negotiated wage solves the following problem:

$$w_i = \text{argmax}(\Omega_i^F)^{1-\phi_i}(\Omega_i^H - \bar{\Omega}_i^H)^{\phi_i}. \tag{3.9}$$

Solving (3.9) for the wage w_i leads to the following expression:

$$\Omega^H - \bar{\Omega}^H = \phi_i\big(\Omega^F + \Omega^H - \bar{\Omega}^H\big). \tag{3.10}$$

By solving (3.9) and with reference to equations (3.1), (3.3) and (3.4)[7], the wage rate of a type i worker results as

$$w_i = b_i + \phi_i(f_{h_i}(z, h_s, h_u) - b_i + \kappa_i(\theta_i)). \tag{3.11}$$

As mentioned before, the resulting wage consists of the compensation of lost leisure, b_i, which could also be interpreted as unemployment

[7] Let Ω_i^S define the total match surplus of the worker (cf. Ljungqvist and Sargent (2000) p. 576); the following conditions have to hold

$$\Omega_i^H - \bar{\Omega}_i^H = \phi_i\Omega_i^S \quad \text{and} \quad \Omega_i^F = (1-\phi_i)\Omega_i^S.$$

Furthermore, the annuity value of an unemployed worker $\frac{r}{1+r}\bar{\Omega}_i^H$ equals

$$\frac{r}{1+r}\bar{\Omega}_i^H = b_i + \frac{\phi_i\kappa_i(\theta_i)}{1-\phi_i}.$$

By applying the above conditions, and with equations (3.1), (3.3) and (3.4), the wage rate of a type i worker follows as in equation (3.11).

benefits, and a fraction ϕ_i of the surplus of the type i worker in excess of benefit payments and the cost of vacancy creation $\kappa_i(\theta_i)$.

By referring to the job creation condition (3.6), the respective wage equation (3.11) and, furthermore, under assumptions concerning the production technology, we can derive an upward sloping wage curve and a downward sloping job creation curve. In general, the wage and job creation curves coincide with the labor supply and labor demand relations, respectively. The equilibrium wage and labor market status of a type i worker is described by figure 3.1 below.

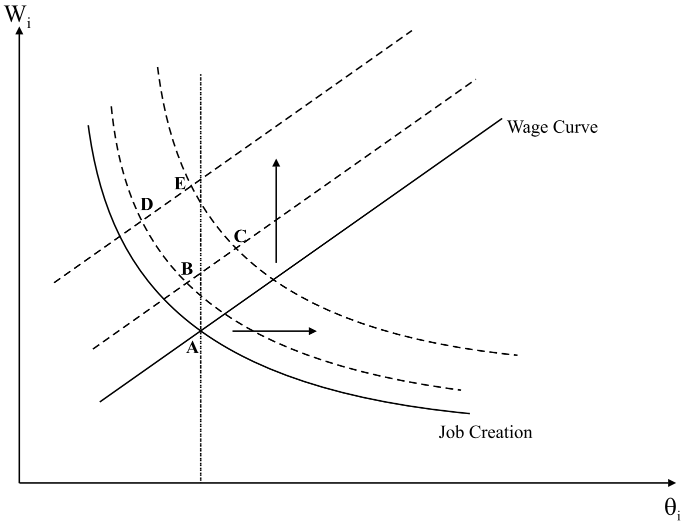

Fig. 3.1. Equilibrium wage and market tightness on the i-th labor market

Under the assumption that the production technology exhibits skill-biased technology effects and that the firm needs both types of skills in production, whereas the workers are imperfect substitutes, figure 3.1 illustrates possible, comparatively static, effects of a change in technology on a type i worker. Because of the fact that the firm needs both types of skill for production, an increase in productivity of one type of worker increases the productivity of the other worker, too, though to a lesser extent. In general, an increase in technology leads to an outward shift of the job creation curve, which results in an increase in θ_i due to the reduction in unemployment and/or an increase in vacancies. The resulting θ_i, w_i relationship can be transformed in the u, v space which represents the equilibrium unemployment-vacancy relation with respect to the job creation-wage relation which is figured out below.

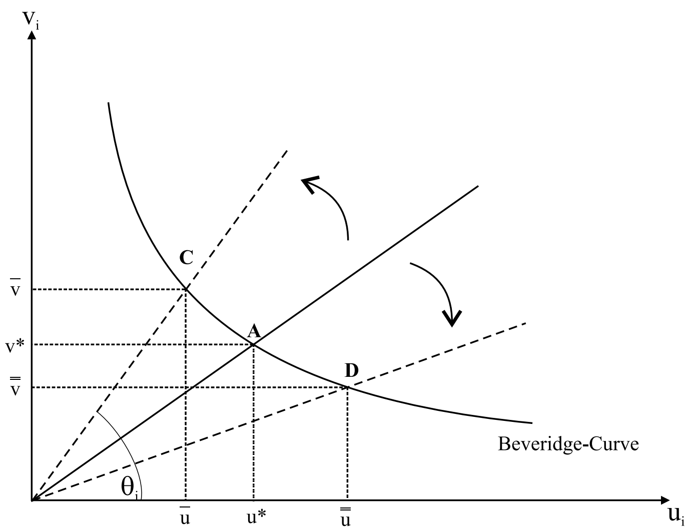

Fig. 3.2. Beveridge curve and labor market equilibrium

Figures 3.1 and 3.2 above describe the effects of advances in productivity on the job creation-wage relation and on the equilibrium unemployment rate. An increase in productivity can lead either to an improvement or a deterioration of the labor market position, which depends in particular on the negotiated wage. In either case, assuming that point **A** denotes the initial equilibrium from which the effects of an advance in technology are studied. An increase in productivity leads, at first, to a higher rate of job creation because of the higher valuation of productive jobs in the future (outward shift of the job creation curve, figure 3.1). If the wage setting curve remains at its position, the vacancy-unemployment ratio increases which leads to a decrease in unemployment (shift from **A** to **C**, figure 3.2). However, high bargaining power or high reservation wages shift the wage curve upwards. Whether the increase in wages is too high, the intersection between the wage and job creation curve is to the left of the initial equilibrium, i.e. at a higher wage rate but at a lower vacancy-unemployment ratio (points **D**,**E**, figure 3.1). The resulting equilibrium unemployment rate is described by the shift from point **A** to **D** in figure 3.2. Similar results are observed if the increase in technology is not high enough in order to compensate too high wage settings.

3.3 Quantitative Analysis

3.3.1 Determinants of Employment

As shown in the previous section, the analytical results for the evolution of employment and wages are rather ambiguous. Therefore, the analysis is extended by numerical calibration.

The two conditions, job creation and the wage curve, will be used in the following to analyze labor market policies concerning the equilibrium outcome, the relative job creation, and the wage spread. In order to model skill biased technological change , two variants of production technologies which account for skill-biased technological change exist.

The first refers to Krusell, Ohanian, Ríos-Rull, and Violante (2000) and is based on the assumption of capital-skill complementarity. This approach differentiates the stock of capital into structure and equipment capital, where the latter is assumed as an imperfect substitute for skilled labor. The second approach is based on Murphy, Riddel, and Romer (1998) and assumes different types of technology which augment either skilled or unskilled labor productivity. The production technology assumed in this thesis refers to a modification of the approach by Murphy, Riddel, and Romer (1998) mentioned by Greiner, Rubart, and Semmler (2004) where only one type of technology is assumed which exhibits different external effects of technological knowledge on the two categories of labor

$$Y_t = \left\{ \gamma_1 \left[z^{\varepsilon_s} (h_s) \right]^{\frac{\sigma-1}{\sigma}} + (1-\gamma_1) \left[z^{\varepsilon_u} h_u \right]^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}}, \tag{3.12}$$

where z denotes the stock of technological knowledge, $\xi_i > 0, i = s, u$ denotes an external effects of knowledge on the productivity of the respective skill group. Furthermore, vacancy costs are assumed of the form $\kappa_i \times \theta_i^{\mu}$, with $0 < \mu \leq 1$. Benefit payments are assumed to ba a fraction of aggregate labor income, i.e. $b = \tau \cdot Y$; for simplicity it is assumed that no government or public transfer system exists. The amount of benefit payments is distributed between both types of workers with a simple sharing rule: the skilled worker receives $b_s = \tilde{\tau} b$ and the unskilled worker $b_u = (1 - \tilde{\tau})b$, with $\tilde{\tau} \in [0, 1]$. As already shown by (3.4) which describes the value of an unemployed worker, the effects of varying unemployment benefits affect the reservation wages of the type i worker. That means, increasing unemployment benefits for low-skilled workers increase their reservation wages and decrease job search activities, which leads to an increase in the relevant unemployment rate. For the following policy experiment the ratio of benefits per output[8], τ is varied in the interval between 0 and 1. The experiment focuses on the comparison of the resulting labor market equilibria, the relative demand for skills, as well as the wage spread.

For the calibration, the ratio of skilled workers is assumed as 30% of the labor force which roughly coincides with the U.S. data. Furthermore, an unemployment rate of skilled workers is assumed as 4%. The remaining fraction, about 70%, of the work force is assumed as low-skilled which, furthermore, exhibits an unemployment rate of 15%. The income share of both types of workers, γ, is assumed as 0.5, and the elasticity of substitution σ is chosen in accordance to the literature, i.e. $\sigma = 1.4$.[9] For both types of workers, we assume symmetrical wage bargaining, i.e. $\phi_s = \phi_u = 0.5$. The results of this calibration are shown in figure 3.3 below.

[8] In general, the analysis outlined in this section could easily be extended to aspects concerning firing costs, employment protection, as, for example, described by Pissarides (2001). The importance of firing costs is, for example, studied by Saint-Paul (1996), chap. 9, or by Kohns (2000). See also chapter 6 for a discussion of labor market policies within a dynamic general equilibrium framework.

[9] See e.g. Heckman, Lochner, and Taber (1998) p. 26.

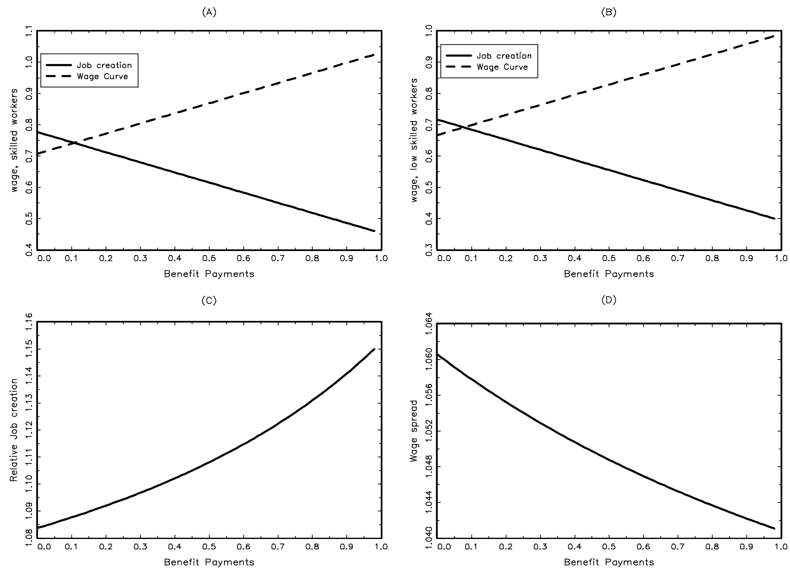

Fig. 3.3. Labor market outcomes of increasing benefit payments

As shown in the upper row of figure 3.3 (A,B), there is a higher equilibrium wage for skilled workers than for low skilled workers. Furthermore, both labor market equilibria exist at a rather low benefit/GDP ratio. Outside (to the right) of this point, job creation is too low to equilibrate the labor market. This situation coincides further with increasing unemployment rates of both types of workers. The lower column of figure 3.3 (C,D) shows the respective relative employment position and the respective wage spread. There one observes a rising job creation in favor of skilled workers which leads to the increase in the relative employment status (figure 3.3, C). That means if benefit payments increase firms create more jobs for skilled workers than for low-skilled workers, because skilled workers are more productive than low skilled workers. On the other hand, increasing benefits reduce the wage spread between the different types of workers because of higher reservation wages which influence the negotiated wage rates.

In general, the results of our model coincide with the observed stylized facts of U.S. and European labor markets. That means, on the one hand a labor market equilibrium at low rates of social benefits as well as higher rates of wage inequality (U.S.) is obtained. Otherwise, increasing benefits lead to a decrease in job creation for low-skilled workers and to an increase in job creation for skilled workers. The latter result coincides with the observed unemployment pattern of low-skilled workers continental Europe (see table 2.1).

3.3.2 Determinants of Wage Inequality

As outlined above, this rather hybrid model is able to generate reasonable employment and wage effects which are consistent with empirical findings for the U.S. and continental Europe. In addition, we have shown how country differences can be discussed within one model framework by parameter variation. However, the relationship between technological change and the labor market remained unclear. Therefore, the aim of this subsection is twofold. First, we try to characterize the effects of technological change on the employment status of each category of worker, second, wee seek to analyze the implications of the wage setting mechanisms on the observed pattern of wage inequality.

In advance of the dynamic general equilibrium models, which will be discussed in the following chapters, the model outlined previously will be extended by a closer consideration of the individual decision behavior. In this extension, we endogenize the reservation option (which coincides with the value of leisure) of the household. By referring to Merz (1995), who modeled labor market with search and matching frictions within a dynamic general equilibrium framework, we define the functional forms of the household's and the firm's decision problem as follows. For simplicity, we assume that a household consists of a continuum of agents which differ in their skill level. Furthermore, the household's members pool their incomes, which leads to a unique consumption-savings decision. The household's preferences are defined in terms of consumption and leisure:[10]

$$U(c_t, h_{s,t}, h_{u,t}) = \frac{c_t^{1-\Phi}}{1-\Phi} - \frac{h_{s,t}^{1-\nu_s}}{1-\nu_s} - \frac{h_{u,t}^{1-\nu_u}}{1-\nu_u} \tag{3.13}$$

The household is assumed to maximize utility according to the following resource constraint:

$$\sum_{i=h,u} c_i + \kappa_i(s_i) = w_u h_u + w_s h_s, \tag{3.14}$$

where $\kappa_i(s_i)$ denotes the search effort an unemployed worker is faced with in order to get a new job.

Applying the functional form of the utility function and the household's budget constraint, the surplus of a type i worker is given by:[11]

$$\Omega_i^H = w_i - U_{h_i}(c_t, h_i) + \kappa_i(s_i). \tag{3.15}$$

As shown by equation (3.15), the net surplus of a worker now consists of the wage, less the disutility of work, given by the partial derivative of the utility function, and the outside option of the worker that are

[10] A detailed description and solution of the household's and the firm's optimization problems is given in section 5.2. Please note, that we abstain for simplicity from capital accumulation.

[11] Equation (3.15) is obtained from the envelope condition, i.e. by taking the derivative of the household's optimization problem with respect to $h_{i,t}$ rather than $h_{i,t+1}$.

determined by unemployment benefits. Furthermore, $\kappa(s_i)$ describes the search costs for unemployed workers which have to be covered by the gain of the new job match.

By referring to the production technology (3.12)), the firm's net surplus of a productive job is obtained in a similar fashion to the household's value of holding a job:

$$\Omega_i^F = f_{h_i}(z, h_i) - w_{i,z} + \frac{a_i}{q_i}(1 - \psi_i). \tag{3.16}$$

Equation (3.16) shows that the net surplus of a firm is given by the marginal product of each type of worker, less the wage and the advertising costs.

By taking equations (3.15) and (3.16) and applying the Nash bargaining criterion, as outlined by (3.9), the respective wage of a skill group follows as:

$$w_s = \psi_h \left[f_{h_s}(\cdot) + a_s \theta_h \right] + (1 - \psi_s) \left[\frac{U_{h_s}(\cdot)}{\lambda} - \kappa_{s_s}(s_s) \right] \tag{3.17}$$

$$w_u = \psi_u \left[f_{h_u}(\cdot) + a_u \theta_u \right] + (1 - \psi_u) \left[\frac{U_{h_u}(\cdot)}{\lambda} - \kappa_{s_u}(s_u) \right]. \tag{3.18}$$

The wage spread between skilled and low skilled workers is obtained by dividing (3.17) by (3.18):

$$\frac{w_s}{w_u} = \frac{\psi_s \left[f_{h_s}(\cdot) + a_s \theta_s \right] + (1 - \psi_s) \left[\frac{U_{h_s}(\cdot)}{\lambda} - \kappa_{s_s}(s_s) \right]}{\psi_u \left[f_{h_u}(\cdot) + a_u \theta_u \right] + (1 - \psi_u) \left[\frac{U_{h_u}(\cdot)}{\lambda} - \kappa_{s_u}(s_u) \right]}. \tag{3.19}$$

For comparison, if we would consider a model with a perfect labor market wage inequality is given by:[12]

$$\frac{w_H}{w_L} = \frac{\gamma_1}{1 - \gamma_1} \left[\frac{A^{\xi}}{A^{\epsilon}} \right]^{\frac{\sigma_p - 1}{\sigma_p}} \left[\frac{H_Y}{L} \right]^{-\frac{1}{\sigma_p}} \tag{3.20}$$

[12] See, Greiner, Rubart, and Semmler (2004) p. 608.

Comparing equations (3.19) and (3.20), it is obvious that, given existence of labor market institutions, wage inequality does not depend on the production technology, external effects of knowledge and the rate of substitution between different skill groups alone. In particular, as will be shown below, the bargaining power of the worker or the trade union has an important effect on wage setting. However, can be seen from equations (3.19) and (3.20) equalize in the case when ψ_i converges to 1, i.e. if there is no sharing rule of the total surplus of a productive job and when no advertising costs of the firms are assumed.

As mentioned above, because of the introduction of further elements into the wage-setting process and the resulting complexity of the obtained equations, makes it difficult to analyze the particular influence of each variable analytically. Therefore, a further calibration experiment is applied to visualize the influences of important variables and parameters. The parameters for the calibration experiment are chosen in accordance with the literature as well as empirical observations. The advertising costs and the substitution elasticity between both types of workers are taken from Merz (1995) and Heckman, Lochner, and Taber (1998). Furthermore, we assume advertising costs for skilled jobs are twice as high than for low-skilled jobs. The employment status of both types of workers coincides with the empirical findings reported in table 2.1. For the v/u ratio, θ, it is assumed that the ratio for skilled workers exceeds the ratio for unskilled workers by factor three. The parameters of the utility function are chosen in accordance with the calibration of the dynamic models presented in the following chapters. In order to obtain quantitative effects of technology we assume a positive 'stock of knowledge', $A > 1$. Furthermore, skill-biased technological change is given by the assumption that ε_s exceeds ε_u.

Table 3.1. Parameter settings

a_s	a_u	γ	ν_s, ν_u	ε_u
0.01	0.005	0.5	0.8	1.1
ε_s	A	θ_s	θ_u	σ
2	2	0.3	0.1	1.4
λ	h_s	h_u	A	
0.001	0.95	0.8	2	

In a first step, we consider how inequality is determined in a perfect labor market, when only parameters of the production technology, i.e. the differences $(\varepsilon_s - \varepsilon_u)$ and the elasticity of substitution determines, σ, affect wage inequality. As can be obtained from figure 3.4 below, two, partly neutralizing effects are at hand. One is the elasticity of substitution, σ, which has dampening effects on wage inequality. The second one is determined by the magnitude of the technology effect which is measured by the difference between ε_s and ε_u). An increasing positive difference increases the productivity of skilled workers and causes, therefor, wage inequality to rise. As, furthermore, shown by figure 3.4, the elasticity of substitution is a crucial parameter with dampening effects on inequality. However, as figure 3.4 shows, if the external effect exceeds a certain amount, inequality starts to increase irrespectively of dampening effects of the value of the substitution elasticity.[13]

[13] The results presented in figure 3.4 are based on parameter variations in equation (3.20).

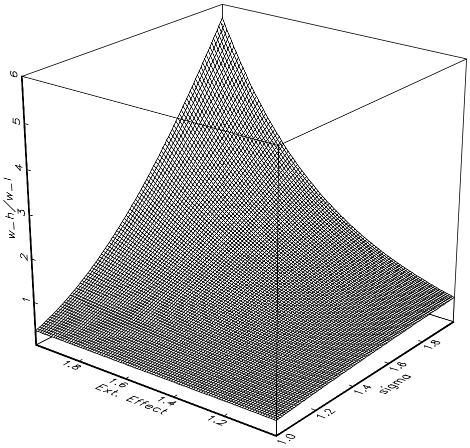

Fig. 3.4. Wage inequality by varying $(\varepsilon_s - \varepsilon_u)$ and σ

When labor market frictions are taken into account, further effects determine wage inequality. Figure 3.5 shows the effects of a varying elasticity of substitution, σ, as well as different levels of bargaining power of low-skilled workers, ψ_u, on wage inequality. The latter assumption accounts for the observation that trade unions determine, in general, the wages of low-skilled workers. The remaining parameters, as well as a positive technology effect, i.e. $\varepsilon_s - \varepsilon_u > 0$, are assumed to be constant.

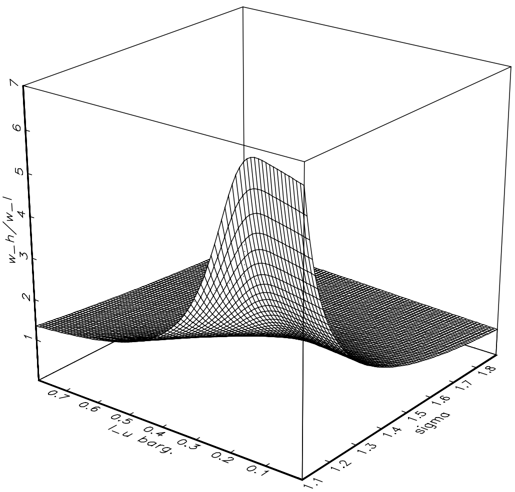

Fig. 3.5. Wage inequality, wage bargaining, varying ψ_u and σ

Figure 3.5 shows that wage inequality is high, if the bargaining power of low-skilled workers is low and the elasticity of substitution between both types of workers is low, too. Comparing the results of figure 3.5 with the empirical findings, one has to state that the results fit the data reasonably; that means that the bargaining power of highly unionized workers (i.e. low-skilled or blue-collar workers) dampens inequality if their power is above a certain level.

The importance of bargaining power is also shown in the third calibration where a varying bargaining power of, both skilled and low-skilled, workers is studied. As in the previous calibration we assume a positive technology effect and an elasticity of substitution, σ which is set as described in table 3.1.

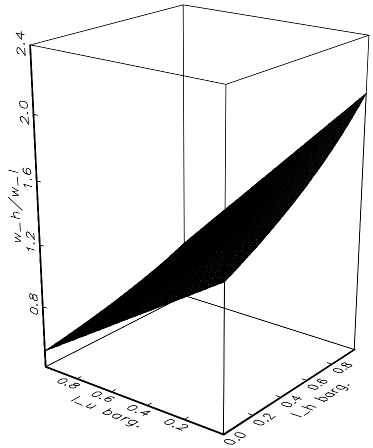

Fig. 3.6. Wage inequality and varying bargaining power

As expected, inequality increases with the bargaining power of skilled workers whereby this effect is dampened when the bargaining power of low skilled workers is high. However, the impact of the bargaining strength depends on the worker's valuation of leisure. When differentiating the equation of the wage spread (3.19) with respect to the bargaining strength of skilled and low skilled workers, ψ_s and ψ_u, we obtain the results of figure 3.6 under the following conditions:

$$\frac{\partial \frac{w_s}{w_u}}{\partial \psi_s} > 0 \qquad \text{if} \qquad f_{h_s} + a_s\theta_s + \kappa_{s_s}(s_s) > \frac{U_{h_s}(\cdot)}{\lambda} \tag{3.21}$$

$$\frac{\partial \frac{w_s}{w_u}}{\partial \psi_u} < 0 \qquad \text{if} \qquad f_{h_u} + a_u\theta_u + \kappa_{s_u}(s_u) > \frac{U_{h_u}(\cdot)}{\lambda}. \tag{3.22}$$

Otherwise, when the worker's valuation of leisure would exceed the worker's value added an increasing bargaining strength leads to opposite results.

3.4 Discussion

In this chapter we outlined the basic framework in order to examine the effects of technological change on employment and wage inequality. Before a complete dynamic version of the recent model framework is studied, the importance and effects of different settings of technological and institutional parameters were described.

In general, we have shown that it is possible to explain the observed cross-country differences of employment and wage inequality within one model framework when different parameter settings are assumed. Based on a basic framework of a labor market which is characterized by search and matching frictions, as described in section 3.2, two important determinants of the unemployment problem could be filtered out: technological change and wage setting institutions. In particular, we have shown that an increase in productivity leads to an increase in job creation, however, this positive effect is dampened if the increase in wages exceeds the productivity gains. By referring to the unemployment pattern of low skilled workers (see e.g. table 2.1), and taking into account that educational wage inequality is rather low in central European countries, the simple comparative static analysis, as described by figure 3.1, explains this observation due to the fact that the increase in low-skilled wages is too high in relation to the respective shift in job creation. As already mentioned, due to the number of parameters and variables, a sole analytical explanation could not give a sufficient explanation of the pattern of relative employment and wage inequality. In a second step, the effects of varying unemployment benefits are considered in order to incorporate the facts concerning labor market institutions and unemployment benefits as reported by tables 2.3 and

2.4. It was shown that an increase in general unemployment benefits or social security payments leads to a relative increase in high-skilled employment and, furthermore, to a decreasing wage spread (see figure 3.3).

In the third step of the calibration experiment, the influence of parameter variations on the resulting wage spread is analyzed under the assumption that wages are determined by a bargaining process. Whereas in a model without wage bargaining the wage spread is determined by the extent of the external effect and the elasticity of substitution (see figure 3.4), further parameters have to be taken into account when a bargaining is assumed. As figures 3.5 and 3.6 show, the resulting wage spread depends crucially on institutional parameters. In addition, the influence of labor market institutions is, in general, able to reduce technological impacts like the external effects of knowledge.

All in all, the theoretical framework outlined in the preceding chapter allows for a more sophisticated analysis of the observed aggregate pattern of wage inequality and relative employment. In particular, the gap between the types of empirical evidence, as reported by microeconometric studies by, for example Fitzenberger (1999) or Puhani (2005), and recent macroeconomic studies on inequality such as Acemoglu (1998), Murphy, Riddel, and Romer (1998), or Krusell, Ohanian, Ríos-Rull, and Violante (2000), and many others has been shortened.

However, the rather static framework discussed in the recent chapter, is not able to account for the dynamic effects of technological advances which we found in the data. That means, the time interval in which an increase in technology leads to an increasing wage spread or to a rising employment level of skilled workers was not considered.

Furthermore, the analysis of this chapter gave no explanation of the cyclical behavior of the key variables such as relative relative employment and wage inequality. Therefore, based on the framework outlined in this chapter, dynamic general equilibrium models are developed in the following chapters in order to discuss the effects of technological change on the observed employment and wage pattern of different skill groups.

4

Inequality and Employment: Basic Framework

Since we claim to have shown in the preceding chapters what determines employment at any point in time it follows, if we are right, that our theory must be capable of explaining the theory of the Trade Cycle.
(J.M. Keynes (1936) p. 313)

4.1 Introduction

Before the dynamic effects of technological change on wage inequality and employment under the assumption of labor market frictions are studied in detail, the logical starting point is to discuss general the integration of labor-force heterogeneity into a dynamic general equilibrium framework. The approach of studying the effects of technological change on employment and wages within a dynamic general equilibrium framework can be seen as a complement to partial equilibrium models of the labor market. In general, no different results to partial equilibrium models are derived, however, this approach offers the opportunity to study the joint behavior of labor market variables and other important variables of the business cycle and the macroeconomic literature such as fiscal policies. As will be seen below, the effects on other variables such as output and investment are considered as well as the time dimension of technological change on the evolution of certain variables are taken into account, too. All in all, the general equilibrium perspective, gives, from the author's point of view, additional insights in the overall diffusion of technological change on important economic variables such as, for example, output and consumption. Furthermore, this framework is generally able to account for a wider class of empirical evidence than partial equilibrium models.

The stochastic dynamic competitive equilibrium model developed below is based on the framework described in the previous chapter. Furthermore, asymmetric technological advances are considered in order to study different effects of technological advances on the employment status and wages of workers who differ in their skills. The structure of the model basically refers to the notion of equilibrium business cycle models introduced by Kydland and Prescott (1982) as well as the extension outlined by Kydland (1984, 1995). The assumption of labor market frictions is relaxed in this chapter. This approach enables us to consider to solely the effects of technological change and the capability of the model to account for the empirical facts.

By following the approach of Kydland (1984), the assumption of heterogenous labor is integrated into a dynamic representative-agent framework, where households decide on the optimal supply of labor and capital and firms choose the profit-maximizing amount of capital and labor for the production of a single output good which can either be consumed or invested. Furthermore, the original framework by Kydland (1984, 1995) is extended by the assumption of different external effects of advances in new technologies on high and low-skilled labor. Furthermore, by referring to the results by Heckman, Lochner, and Taber (1998) or Rowthorn (1999), the assumed production technology is characterized by imperfect substitution between both types of labor as well as between labor and physical capital.

Because of the assumption of external effects of new technologies, as introduced by Greiner, Rubart, and Semmler (2004), the recent approach provides an alternative to the capital-skill hypothesis studied by Krusell, Ohanian, Ríos-Rull, and Violante (2000) and Lindquist (2004). In particular, the latter study is the one to refer to in order to study the business cycle properties of the skill-biased technological change hypothesis.

The remainder of this chapter is structured as follows. Section 4.2 outlines the stochastic dynamic general equilibrium (SDGE) framework of the model described above. In section 4.3, the equilibrium solution will be derived, which will be further calibrated with respect to empirical evidence. Finally, in sections 4.4 and 4.5 the obtained results will be discussed.

4.2 A Model Without Market Frictions

The model consists of two types of agents, a representative household and representative firms which produce a homogeneous output good. It is assumed that the household consists of a continuum of agents, i.e. skilled and unskilled workers which are separated from each other and who pool their incomes. Furthermore, the household owns all factors of production and all shares of the firms. The distribution of skills is fixed by assumption and does not change over time; the endowment of physical capital is equally distributed across all members of the household. The assumption of a representative household that is faced with a single budget constraint reduces the complexity of the model's solution. Otherwise, if a multiagent model were considered, the solution of the model would depend on the correct law of motion of the distribution of the economy's agents. In this case the distribution becomes a state variable which leads, as outlined for example by Ríos-Rull (1995), to computational problems and prevent the use of several solution methods.[1]

The interaction of the economic agents is described as follows. Each period, the household sells factor services, i.e. skilled and unskilled labor as well as physical capital to the firms. The single good which is produced by the firms can either be consumed or invested in physical capital. Firms owned by the households hire capital and labor in order to produce output each period. The output is sold back to the household and all profits are returned to the shareholders. Finally, as outlined by Stokey and Lucas (1989), all transactions take place in a single once-and-for-all market that meets in period $0, 1, 2, ... \ T$. There, all trading takes place such that all prices and quantities are determined simultaneously. After the market has closed, agents deliver and receive the quantities of factors and goods they have contracted to sell or to buy respectively.[2]

The Household

As already mentioned, the total population consists of skilled and unskilled workers, which are separated from each other, i.e. unskilled workers cannot become skilled and vice versa.[3] Furthermore, total pop-

[1] A detailed discussion of the solution of heterogeneous agents models can be found in Ríos-Rull (1995). Further solution strategies and computational methods for heterogeneous agents models can be found in Ríos-Rull (1999).

[2] See Stokey and Lucas (1989) p. 23 f. for further details.

[3] This assumption simplifies the analysis and is rather consistent with the fact that unskilled workers cannot become skilled within the period of one or two quarters. For example, a study which concentrates on the schooling decision of workers within an overlapping generations (OLG) framework can be found in Heckman, Lochner, and Taber (1998).

ulation is normalized to one, i.e. $u + s = 1$, where u and s denote the measures of unskilled and skilled workers. Each agent is endowed with one unit of time, i.e. hours worked by an agent of type $i = s, u$, $h_{i,t} = 1 - n_{i,t}$, where $n_{i,t}$ denotes the leisure time of the respective agent. The total number of hours worked by the respective type of workers follows as $h_{s,t} = s \cdot (1 - n_{s,t})$ for skilled workers and $h_{u,t} = u \cdot (1 - n_{u,t})$ for unskilled workers. Furthermore, because of the assumption that skilled and unskilled workers are members of a single household, we assume that both pool their income which leads to a single consumption / savings decision.

The household derives utility from consuming a single consumption good, c_t, and from leisure activities of the respective skill group. The preferences of the household are described by an additively time separable utility function. Time separability means that the marginal utility of consumption at date t is independent of the marginal utility at other dates. Furthermore, the utility function $U\left(c_t, h_{s,t}, h_{u,t}\right)$ is assumed as twice continuously differentiable in all arguments, strictly concave and satisfying the Inada conditions, i.e.

$$\lim_{c \to 0} U_c(\cdot) = \lim_{h_s \to 0} U_{h_s}(\cdot) = \lim_{h_u \to 0} U_{h_u}(\cdot) = \infty$$

and

$$\lim_{c \to \infty} U_c(\cdot) = \lim_{h_s \to \infty} U_{h_s}(\cdot) = \lim_{h_u \to \infty} U_{h_u}(\cdot) = 0.$$

The members of the household receive wage income, i.e. w_u and w_s, as well as capital income r_t from lending capital k_t to firms. The optimal decision problem of the household follows as:[4]

[4] Please note that there are two ways to solve this kind of intertemporal models: the approach via the value function as in Stokey and Lucas (1989), or directly via the Lagrange function as proposed by Chow (1997). In this book I follow the latter approach.

$$\max_{c_t, h_{i,t}} E_t \left[\sum_{t=0}^{\infty} \beta^t U\big(c_t, h_{s,t}, h_{u,t}\big) \right] \tag{4.1}$$

subject to

$$c_t + I_t = r_t k_t + w_{s,t} s h_{s,t} + w_{u,t} u h_{u,t} \tag{4.2}$$

$$k_{t+1} = (1-\delta) k_t + I_t, \tag{4.3}$$

where (4.2) describes the household's budget constraint and (4.3) denotes the law of capital accumulation. Furthermore, I_t is defined as gross investment in physical capital and the parameter $0 \leq \delta \leq 1$ denotes the depreciation rate.

The household's decision problem, as outlined by equations (4.1)-(4.3), leads to the following Lagrange function:

$$\begin{aligned} \max_{c_t, h_{i,t}} \mathcal{L}^H = E_t \sum_{t=0}^{\infty} \beta^t \Big[& U(c_t, h_{s,t}, h_{u,t}) \\ & + \lambda_t \big[w_{s,t} s h_{s,t} + w_{u,t} u h_{u,t} \\ & + r_t k_t - c_t - k_{t+1} + (1-\delta) k_t \big] \Big], \end{aligned} \tag{4.4}$$

which yields the following first order conditions[5]

$$U_c(\cdot) = \lambda_t \tag{4.5}$$

$$U_{h_s}(\cdot) = \lambda_t w_{s,t} \tag{4.6}$$

$$U_{h_u}(\cdot) = \lambda_t w_{u,t} \tag{4.7}$$

$$1 = \beta E_t \frac{U_{c,t+1}(\cdot)}{U_{c,t}(\cdot)} (1 + r_{t+1} - \delta), \tag{4.8}$$

where $(1 + r_{t+1} - \delta)$ denotes the return of capital, determined by the interest rate r_{t+1} and the depreciation rate δ. Furthermore, λ_t denotes the Langrange multiplier associated with the household's resource constraint.

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

The Firms

If the price of the output good p_t is normalized to 1, the problem of the firms is to choose the profit-maximizing demand for factor inputs per period given the prices for skilled and unskilled labor as well as physical capital, $w_{s,t}, w_{u,t}, r_t$, i.e.[6]

$$\max_{h_{s,t}, h_{u,t}, k_t} \Pi_t = (y_t - w_{u,t} h_{u,t} - w_{s,t} h_{s,t} - r_t k_t) \,, \tag{4.9}$$

subject to

$$y_t \leq f(k_t, h_{s,t}, h_{u,t}, z_t). \tag{4.10}$$

Concerning the production technology $f(k_t, h_{s,t}, h_{u,t}, z_t)$, it is assumed that it is twice continuously differentiable in its arguments, it exhibits positive and diminishing marginal products of its inputs, it is strictly concave and it satisfies the Inada conditions, i.e.

$$\lim_{k \to 0} f_k(\cdot) = \lim_{h_s \to 0} f_{h_s}(\cdot) = \lim_{h_u \to 0} f_{h_u}(\cdot) = \infty$$

and

$$\lim_{k \to \infty} f_k(\cdot) = \lim_{h_s \to \infty} f_{h_s}(\cdot) = \lim_{h_u \to \infty} f_{h_u}(\cdot) = 0$$

Furthermore, z_t represents the state of technology which is assumed to follow a stationary first order autoregressive process, as described by the following law of motion

$$z_{t+1} = \omega z_t + \epsilon_{t+1}^z, \tag{4.11}$$

with $\epsilon_t^z \sim i.i.d.\ \mathcal{N}(0, \sigma_z^2)$ and $\omega \in [0,1]$.

The solution of the firm's optimization problem (equations (4.9) and (4.10)) leads to the optimal factor demands as well as to the result that factor prices equal their marginal products

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[6] Stokey and Lucas (1989) describe the firm's problem as a sequence of one period maximization problems. Cf. Stokey and Lucas (1989) p. 25.

$$r_t = f_k(\cdot) \tag{4.12}$$

$$w_{s,t} = f_{h_s}(\cdot) \tag{4.13}$$

$$w_{u,t} = f_{h_u}(\cdot). \tag{4.14}$$

4.3 General Equilibrium

Following Stokey and Lucas (1989), a competitive equilibrium of this economy is characterized by a set of prices $\{(r_t, w_{s,t}, w_{u,t})\}_{t=0}^{\infty}$ as well as an allocation[7] $\{(k_t^d, h_{s,t}^d, h_{u,t}^d, y_t)\}_{t=0}^{\infty}$ for the representative firm and an allocation $\{(c_t, I_t, k_{t+1},$
$k_t^s, h_{s,t}^s, h_{u,t}^s)\}_{t=0}^{\infty}$ for the representative household, such that at the stated prices[8]

1. $\{(k_t^d, h_{s,t}^d, h_{u,t}^d, y_t)\}_{t=0}^{\infty}$ solves the maximization problem of the firm, given by equations (4.9) and (4.10).
2. $\{(c_t, I_t, k_{t+1}, k_t^s, h_{s,t}^s, h_{u,t}^s)\}_{t=0}^{\infty}$ solves the household's problem, given by (5.9) - (5.11).
3. all markets clear, i.e.
   $k_t^d = k_t^s$, $h_{s,t}^d = h_{s,t}^s$,$h_{u,t}^d = h_{u,t}^s$, $c_t + I_t = y_t$, $\forall\ t$.

From the first-order conditions of the households and the firm's optimization problems (see equations (4.5)-(4.8) and (4.12)-(4.14), the following optimality conditions are derived:

$$U_{h_s}(\cdot) = -U_c(\cdot) \cdot f_{h_s}(\cdot)s \tag{4.15}$$

$$U_{h_u}(\cdot) = -U_c(\cdot) \cdot f_{h_u}(\cdot)u \tag{4.16}$$

$$1 = E_t\beta\Big[\frac{U_{c,t}}{U_{c,t+1}}R_{t+1}\Big], \tag{4.17}$$

[7] Please note that the superscripts $()^d$ and $()^s$ characterize the demand and the supply of a variable, respectively.

[8] Cf. Stokey and Lucas (1989) p. 25.

with $R_{t+1} = f_{k_{t+1}}(\cdot) + 1 - \delta$.

The aggregate resource constraint is given by

$$c_t + I_t = w_{s,t} s h_{s,t} + w_{u,t} u h_{u,t} + r_t k_t. \tag{4.18}$$

Finally, the solution of the model is a set of variables

$$\Omega = \left\{c_t, I_t, y_t, k_{t+1}, h_{s,t}, h_{u,t}, z_t\right\} \tag{4.19}$$

determined by equations (4.3), (4.10), (4.11) and equations (4.15)-(4.18). Furthermore, the following variables are introduced in the examination although they are not necessary for the solution: the relative employment status of different skill groups and the spread of wages.

4.4 Numerical Analysis

4.4.1 Function Specification

In this section the model will be solved numerically for its deterministic steady state. This solution will be applied for a linear approximations of the nonlinear equations around its steady state. Economically the steady state of a model is interpreted as the long-run equilibrium where all variables grow at the same rate.[9] Because of the assumption that the population remains constant and the assumption that technological change exhibits no constant growth rate, no transformation of variables is necessary. In the following it is abstained from the analytical derivation of the steady states, because the used computer algorithm which is able to calculate the steady state of the model numerically.

[9] Mathematically the steady state is defined as a fix point of a system of dynamic equations, for example, the following condition has to hold when a steady state is calculated:

$$x_{t-1} = x_t = \bar{x}.$$

A description how to find the steady states of a dynamic general equilibrium model analytically can be found in Uhlig (1999) or Heer and Maussner (2005).

Before the model is solved numerically, the functional forms of the household's preferences and the production technology have to be defined.

The preferences of the representative household are described by the following utility function:

$$U(c_t, h_{s,t}, h_{u,t}) = \frac{c_t^{1-\Phi}}{1-\Phi} - \frac{h_{s,t}^{1-\nu_s}}{1-\nu_s} - \frac{h_{u,t}^{1-\nu_u}}{1-\nu_u} \tag{4.20}$$

with $\Phi, \nu_1, \nu_2 \geq 0$, where Φ denotes the intertemporal substitution elasticity of consumption and ν_1, ν_2 represent the respective elasticities for the supply of labor.

The production technology is specified in order to capture the existence of substitution elasticities different to one between both types of labor as well as between labor and capital. In particular, the production technology is assumed to be analogous to Heckman, Lochner, and Taber (1998):

$$f(\cdot) = z_t \left(\alpha\left(\gamma(z_t^{\xi_s} h_{s,t})^{\rho_1} + (1-\gamma)(z_t^{\xi_u} h_{u,t})^{\rho_1}\right)^{\frac{\rho_2}{\rho_1}} + (1-\alpha)k_t^{\rho_2}\right)^{\frac{1}{\rho_2}}, \tag{4.21}$$

where $\rho_1, \rho_2 > 0$ determine the substitution elasticities given by $\frac{1}{1-\rho_i}$ and, furthermore, $0 < \alpha, \gamma < 1$ determine the respective income shares of total labor as well as the income share of the respective skill group. First, the production technology accounts, as mentioned above, for substitution elasticities different to one; secondly, skill-biased technological change is introduced by external effects of technological change due to the parameters $\xi_s, \xi_u > 0$. This alternative representation, introduced by Greiner, Rubart, and Semmler (2004), concentrates on the impact of technology rather than capital-skill complementarity as introduced by Krusell, Ohanian, Ríos-Rull, and Violante (2000), which is also considered in a business cycle framework by Lindquist (2004).

Furthermore, we introduce asymmetric technology shocks by assuming three different types of technologies: $z_t, \breve{z}_t$, and $\tilde{z}_t$, where $\breve{z}_t$ denotes a skill-biased shock and $\tilde{z}_t$ a low-skill-biased one. Then, the production technology rewrites to

$$f(\cdot) = z_t \left(\alpha\big(\gamma(\breve{z}_t^{\xi_s} h_{s,t})^{\rho_1} + (1-\gamma)(\tilde{z}_t^{\xi_u} h_{u,t})^{\rho_1}\big)^{\frac{\rho_2}{\rho_1}} + (1-\alpha)k_t^{\rho_2}\right)^{\frac{1}{\rho_2}} . \tag{4.22}$$

Because of the assumption of perfect labor markets, wages are determined by the marginal product of skilled and unskilled labor, i.e.

$$w_{s,t} = \gamma z_t^{1+\xi_s \rho_2} \Delta_{1,t}^{\frac{1}{\rho_2}-1} \cdot \Delta_2^{\frac{\rho_2}{\rho_1}-1} h_{s,t}^{\rho_2 - 1} \tag{4.23}$$

$$w_{u,t} = (1-\gamma) z_t^{1+\xi_u \rho_2} \Delta_{1,t}^{\frac{1}{\rho_2}-1} \cdot \Delta_2^{\frac{\rho_2}{\rho_1}-1} h_{u,t}^{\rho_2 - 1} \tag{4.24}$$

with

$$\Delta_{1,t} = \alpha\big(\gamma(z_t^{\xi_s} h_{s,t})^{\rho_2} + (1-\gamma)(z_t^{\xi_u} h_{u,t})^{\rho_2}\big)^{\frac{\rho_2}{\rho_1}} + (1-\alpha)k_t^{\rho_2} \tag{4.25}$$

$$\Delta_{2,t} = \gamma(z_t^{\xi_s} h_{s,t})^{\rho_2} + (1-\gamma)(z_t^{\xi_u} h_{u,t})^{\rho_2} \tag{4.26}$$

The wage differential between both types of workers is obtained by dividing equation (4.23) by equation (4.24):

$$\tilde{w}_t = \frac{w_{s,t}}{w_{u,t}} = \frac{\gamma}{1-\gamma} \left[\frac{z_t^{\xi_s}}{z_t^{\xi_u}}\right]^{\rho_1} \left[\frac{h_{s,t}}{h_{u,t}}\right]^{\rho_1 - 1} . \tag{4.27}$$

The relative employment share of both skill groups is defined as

$$\tilde{h}_t = \frac{h_{s,t}}{h_{u,t}}. \tag{4.28}$$

4.4.2 Calibration

The focus of the preceding section is to derive insights into the model's ability to reproduce stylized facts of the business cycle, measured by the correlation of a set of variables with GDP, and to derive impulse response functions which indicate the behavior of the model's variables, in particular employment and wages, after an unanticipated technology shock.

In order to conduct the analysis outlined above, it is necessary to transform the system of equations given by (4.3), (4.10), (4.11), (4.15)-(4.18) as well as the functional forms as defined in (4.20), (4.21), (4.27) and (4.28), to a system of linear equations. A linearized system of the above equations is obtained by a first-order Taylor series expansion around the deterministic steady state as proposed by Juillard (1996) as well as Collard and Juillard (2001).[10] The deterministic steady states of the model are computed numerically by a Newton-Raphson method provided by DYNARE.[11]

The parameters chosen for the calibration experiment are reported in table 4.1 below.

[10] In general, Collard and Juillard (2001) propose higher-order Taylor series approximations. For computational reasons and because of the fact that second-order approximations do not change the results, the first-order approximation is chosen.

[11] A brief description of DYNARE is given in appendix D.

Table 4.1. Parameter settings

α	γ	s	u	β
0.64	0.5	0.25	(1-s)	0.99
δ	Φ	ν_s	ν_u	ρ_1
0.025	0.5	0.8	0.8	0.3
ρ_2	ξ_s	ξ_u	ω	
0.1	1.4	1.0	0.95	

The parameters are chosen in accordance with the empirical evidence, $\alpha = 0.64$ denotes the labor's share of total income, the income distribution between both skill groups, determined by γ, is assumed to be equal. The amount of skilled workers of an economy is assumed to be 25% and is consistent measures for the U.S., where the ratio of employees who have earned some college degree was reported to be 28% in 2002 (see table 2.1). The parameters β, δ, and Φ are chosen in accordance with the literature. The labor supply elasticities ν_s, ν_u are assumed equal. Their parametrization is chosen in accordance with Chari, Kehoe, and McGrattan (2000). The elasticity of substitution between both types of labor ρ_1 is calibrated in order to replicate the empirical measures which report a substitution elasticity of 1.4[12], furthermore the elasticity of substitution between labor and physical capital is assumed to be close to unity as reported by Heckman, Lochner, and Taber (1998). Concerning the external effects of technology ξ_s, ξ_u, it is assumed that skilled workers are 40% more productive than low-skilled workers, which coincides with the measures of Greiner, Rubart, and Semmler (2004).

[12] Cf. Heckman, Lochner, and Taber (1998) p. 26.

The following figures summarize the obtained responses of output, wages and the employment status of both kinds of workers due to unanticipated advances in neutral, skill- and low-skill-biased technology.

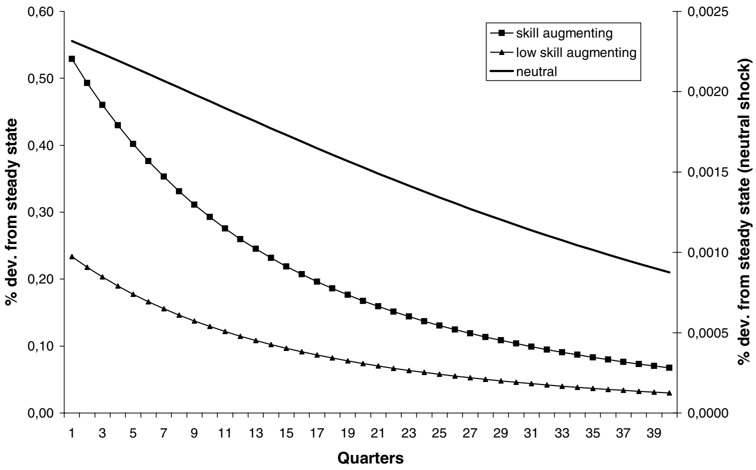

Fig. 4.1. Output responses of different technology shocks

An increase in any type of productivity leads to a positive response of output and employment of both skill groups.[13] However, the output response of a neutral shock is as high as its calibrated standard deviation, whereas the response of a skill-biased technology shock exceeds the latter by a factor of 10 to 20. As shown below, a neutral shock leads to only a small increase in employment. Because of the slight increase in employment, the output expansion is negligible, too.

Beside the question whether a neutral or a more skill-enhancing productivity shock leads to a higher response of output, the main interest should be focussed on the response of the relative employment position

[13] The same holds for consumption and investment activities.

and the wage spread. Figures 4.2 and 4.3 below show the effects of the different technological advances on the wage spread as well as the relative employment position.

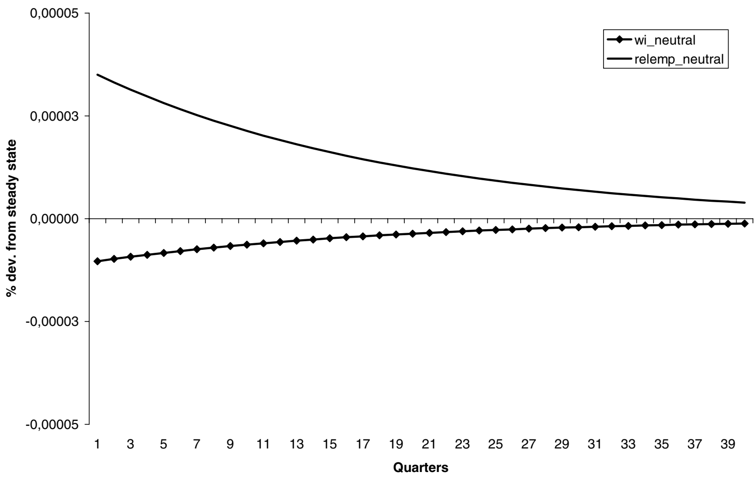

Fig. 4.2. Responses of a neutral technology shock

As shown in figure 4.2, a neutral shock in technology forces the relative employment ratio to increase, i.e. employment of skilled workers increases more than employment of low skilled workers. At the same time, the wage spread is forced to decline (diamonds). This effect is caused by the fact that the immediate decline in the marginal product of skilled workers due to the higher increase in employment leads to a relative decline in the wage spread under a neutral technology shock. In addition, the neutral increase of technology, i.e. the productivity of both types of workers, is affected similarly, which forces the factor demands and prices to behave rather equally.

A significant change in the magnitude of the observed responses is found when either skill- or low-skill-biased technology shocks are considered (figure 4.3, below). There, we observe the expected responses of wage inequality and the relative employment position. A skill-biased technology shock forces the employment of skilled workers to increase (dashed line). Due to the higher productivity, the respective marginal products tend to increase, too, which leads to an immediate increase in wage inequality (black diamonds). The reverse pattern is observed after an unanticipated increase in low-skill-biased technology. There, inequality and relative employment exhibit a negative response. In comparison to a skill-biased shock, the magnitude as well as the persistency of the adjustment pattern, one has to state that the effect of a skill-biased shock is greater than a low-skill-biased one. A further important question, especially when looking at continental European labor markets concerns the demand for low skilled labor. Figure 4.4 below shows the adjustment processes of the demand for low-skilled labor.

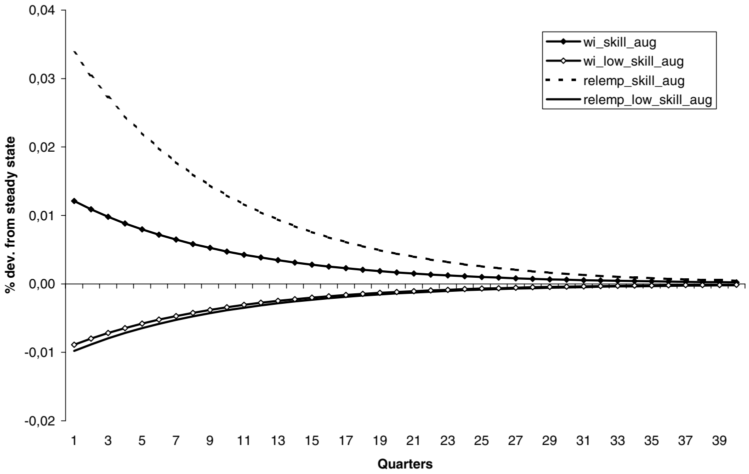

Fig. 4.3. Responses of skill- and low-skill-biased shocks

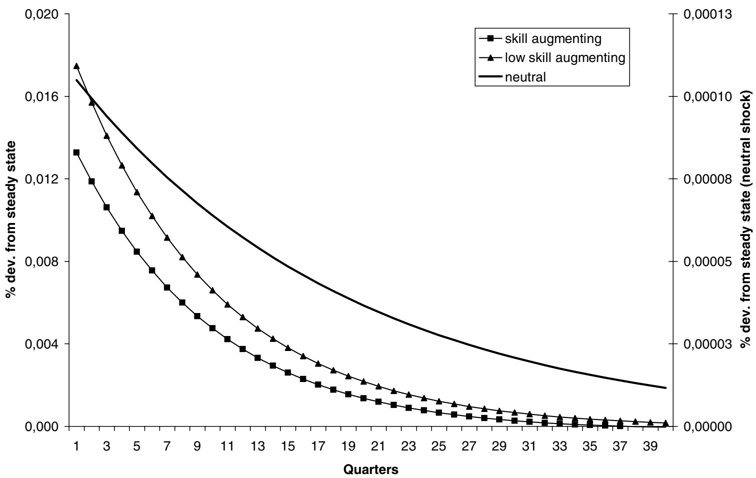

Fig. 4.4. Employment position of low-skilled workers

As outlined, for example in table 2.1 or by the empirical findings of Puhani (2005), the demand for low-skilled workers decreased significantly during the 1980s for continental European countries. The prediction of the model concerning the demand for low-skilled workers after asymmetric technology shocks is that the demand increases (figure 4.4). The behavior of the responses is determined by the assumed production technology, in which the factor demand depends on the amount and the productivity of the other production factors, too. That means when a rise in productivity os skilled workers is at hand, the productivity of low skilled workers increases to, however, at a lower degree.

Finally the question is raised whether the models are capable of reproducing basic facts of the business cycle. Table 4.2 below reports the empirical findings for the U.S. and Germany. 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, the fluctuation of real wages in Germany is, compared to the U.S., rather low ($.40 < .90$), too. An important difference is observed for the volatility of the wage spread: for Germany a rather stable wage spread is reported whereas one observes a volatile variable for the U.S. ($0.16 < 0.82$). Furthermore, we observe a negative correlation between the wage spread and output for both countries. The same finding holds for the relative employment position.

Table 4.2. 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					
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

Correlation of Observed Variables

Although the negative output-employment correlation found for the German data surprises, this result can be explained by the fact that the considered employment data refer to the West-German manufacturing sector which reduced any type of employment during the considered time period. However, the positive correlation between the relative employment ratio and output shows, as expected, a positive sign.

Table 4.3. Business cycle properties of the RBC-type model

	Relative	Correlation of Simulated Variables								
	Volatility	y	c	i	n_s	n_u	n_s/n_u	w_s	w_u	w_s/w_u
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

Comparing the reported correlations with the empirical findings, it is obvious that the output correlation of the employment and wages is much higher than found in the data. Furthermore, one finds a negative correlation between output and low skilled employment which is not found in the simulation results. Furthermore, the negative correlation between employment and wages is also not found in the model. However, the high correlation of low and high-skilled employment which is reported by the German data is reproduced by both models as well as the relationship between both types of wages is reproduced quite well.

4.5 Discussion

In recapitulating the discussion of the wage spread the reader is, in general, referred to the long-run perspective of endogenous growth models with perfect labor markets, for example Murphy, Riddel, and Romer (1998), Krusell, Ohanian, Ríos-Rull, and Violante (2000), or Acemoglu (1998).[14] However, the results of the recent chapter show that the assumption of a perfect labor market is insufficient in order to reproduce the empirical pattern of wage inequality and relative employment.

As reported by the empirical analysis in section 2.3.2, wage inequality and relative employment exhibit a delayed or hump-shaped response to shocks in technology. However, as shown by figures 4.1 – 4.4, neutral and skill-biased technological advances lead to an immediate increase in wage inequality and the relative employment position, whereas an unanticipated shock in low-skill-biased technology leads, as expected, to the opposite effect. Furthermore, in order to reproduce the findings for continental European labor markets, a skill-biased technology shock should lead to a decline in the demand for low-skilled labor. However, the reported employment response of low skilled workers is always positive (see figure 4.4).

When comparing the simulated correlation coefficients to their empirical counterparts (tables 4.2 and 5.2), the model reproduces the counter-cyclical pattern of the wage spread, however to a greater extent than is found in the data.[15] In addition, the negative correlation of the relative employment status is not reproduced by the model. The latter

[14] A notable exception is Acemoglu (1999), where the determinants of wage inequality are combined with the assumption of imperfect labor markets.

[15] The counter-cyclical correlation of output and the wage spread is also reported by Skaksen and Sorensen (2005), who develop an empirical model with capital-skill complementarity for the U.S. and Denmark.

result is explained by the effect that the skill-biased technology shocks dominate the employment pattern in this economy, i.e. the level of employment increases immediately for both types of workers, although the employment position of skilled-workers increases to a greater extent. The immediate positive response of output and relative employment leads to this pro-cyclical correlation of output and employment.

All in all, the extension of a Kydland and Prescott (1982) style competitive equilibrium model which is extended by two types of workers and asymmetric technology shocks does not lead to a better explanation of the observed pattern of wage inequality and relative employment. In particular, it does not provide a reasonable explanation for the increase in low-skilled unemployment which is reported for continental European countries. Therefore, the aim of the following chapters is to develop a model in which one is enabled to discuss involuntary unemployment. In addition, in order to account for central European labor market institutions, market frictions and a general form of a wage setting mechanism are introduced into the described dynamic general equilibrium framework.

5

Inequality and Employment Under Labor Market Frictions

> *DSGE models have come a long way since Kydland and Prescott (1982) in incorporating labor-market frictions and giving correspondingly more realistic portrayals of the economy. Recognition of the heterogeneity of workers and jobs has been central to this improvement in macro modelling.*
> *(R.E. Hall (1999) p. 1167)*

5.1 Introduction

The impact of skill-biased technological change has already been discussed by Acemoglu (1999), Mortensen and Pissarides (1999) or in a recent paper by Hornstein, Krusell, and Violante (2005). However, a concentration on the long-run impact of skill-biased technological change (as in Acemoglu (1999)), or on partial equilibrium models like Mortensen and Pissarides (1999) does not seem sufficient in order to account for the observed unemployment pattern. For example, long-run growth models do not account for business cycle fluctuations of important variables and, furthermore, partial equilibrium models do not account for capital accumulation and possible substitution effects between certain variables such as capital and labor.

In order to study the relationship between skill-biased technology shocks and the employment status of different skill groups the dynamic general equilibrium framework of the previous chapter is extended by a labor market which is characterized by search and matching frictions and wage bargaining (see chapter 3.2). The importance of such frictions, in particular wage bargaining schemes, in order to explain the outcomes of European labor markets is highlighted by the study of de la Croix, Pfalm, and Pfann (1996). In general, a similar line of research can be found in the work by Ljungqvist and Sargent (1998), Mortensen and Pissarides (1999), 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, households' labor-leisure choice as well as low-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, which means that skilled and unskilled workers can apply to skilled and unskilled jobs, only. This assumption simplifies the analysis and is in line with recent empirical results by Gottschalk and Hansen (2003). In addition to the examination of impulse-response functions, the analysis of this chapter concludes with a comparison of the obtained results with the outcome of a model without labor market frictions. There, it will be shown that a model with labor market frictions improves the ability of the model with a frictionless labor market to reproduce the empirical facts and the obtained impulse-response functions of a variety of technology shocks. In particular, it will be shown that a neutral technology shock leads to a hump-shaped or delayed response of the variables. This might explain why the IT revolution fostered economic activity in the U.S. relatively fast whereas the initial impact of the introduction of new technologies appeared delayed in continental European countries.

The remainder of this chapter is organized as follows. Section 5.2 outlines the market structure of the model. In section 5.3 we present the equilibrium solution and the calibration of the model. Section 5.4 presents the obtained results, and section 5.5 concludes with a short discussion.

5.2 The Model

Market Structure of the Model

The model outlined below is based on the seminal work by Merz (1995), Langot (1995), on suggestions made by Cahuc and Zylberberg (2004)[1], and Greiner, Rubart, and Semmler (2004). The model economy consists of two sectors a household and a production sector. The household sector 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 $0 < \psi_i < 1$ with $i = s, u$ and $\psi_s < \psi_u$. Furthermore,

[1] See Cahuc and Zylberberg (2004), chap. 10.

we assume a two-sided search process, i.e. both unemployed workers of each skill group and firms with vacant jobs seek new job matches.

The Labor Market

The economy's labor force is assumed to be constant and is normalized to one. Let $l_{i,t}$ 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

$$h_{s,t+1} = (1 - \psi_s)h_{s,t} + M_{s,t} \tag{5.1}$$

$$h_{u,t+1} = (1 - \psi_u)h_{u,t} + M_{u,t}, \tag{5.2}$$

where $\psi_i \in (0, 1)$ denotes the exogenous rate of job destruction and $M_{i,t}$ gives the number of newly created jobs in period t for a type i worker. New job matches are created through a linear-homogeneous matching technology,

$$M_i = M(s_{i,t}u_{i,t}, v_{i,t}). \tag{5.3}$$

As mentioned above, 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 equation 5.3 implies the following transition probabilities from unemployment to employment and from an unfilled to a filled job vacancy of type i:

$$p_{i,t} = \frac{M_{i,t}}{s_{i,t}(1 - h_{i,t})} \tag{5.4}$$

$$q_{i,t} = \frac{M_{i,t}}{v_{i,t}}. \tag{5.5}$$

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

$$\theta_{s,t} = \frac{v_{s,t}}{(1 - h_{s,t})} \tag{5.6}$$

$$\theta_{u,t} = \frac{v_{u,t}}{(1 - h_{u,t})}. \tag{5.7}$$

With the definition of $l_{i,t} = u_{i,t} + h_{i,t}$ 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.

$$\tilde{u}_{i,t} = 1 - \tilde{h}_{i,t}. \tag{5.8}$$

The Household Sector

We assume a representative household with a large number of members 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 lifetime utility. Households receive income from lending capital to firms at the interest rate r_t and from having a fraction of both types of their members $n_{i,t}$ work at the respective wage rates $w_{i,t}$. The household's maximization problem reads as follows:

$$U_t = \max_{c_t, s_{i,t}} \sum_{t=0}^{\infty} \beta^t U(c_t, h_{s,t}, h_{u,t}) \tag{5.9}$$

subject to

$$\sum_i w_{i,t} h_{i,t} + r_t k_t = c_t + I_t + \sum_i \kappa_i(s_{i,t})(1 - h_{i,t}) \tag{5.10}$$

$$k_{t+1} = (1 - \delta)k_t + I_t \tag{5.11}$$

$$h_{s,t+1} = (1 - \psi_s)h_{s,t} + p_{s,t}s_{s,t}(1 - h_{s,t}) \tag{5.12}$$

$$h_{u,t+1} = (1 - \psi_u)h_{u,t} + p_{u,t}s_{u,t}(1 - h_{u,t}), \tag{5.13}$$

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 probability at which 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 complete insurance against the loss of income during unemployment (cf. Merz (1995) p. 273). Furthermore, this assumption leads to a single consumption-savings (investment) decision of the household which also simplifies the solution of the model.

The household's maximization problem, given by equations (5.9)–(5.13), leads to the following Lagrange function:

$$\begin{aligned}\max_{c_t, s_{i,t}} \mathcal{L}^H = E_t\Big\{ \sum_{t=0}^{\infty} \beta^t \Big[& U(c_t, h_{s,t}, h_{u,t}) \\ & + \lambda_t \Big(\sum_{i=s,u} w_{i,t} h_{i,t} + (1 + r_t - \delta) k_t - c_t \\ & - k_{t+1} - \sum_{i=s,u} \kappa_i(s_{i,t}) \Big) \\ & + \xi_{1,t} \big(h_{s,t+1} - (1 - \psi_s) h_{s,t} - p_{s,t} s_{s,t} (1 - h_{s,t}) \big) \\ & + \xi_{2,t} \big(h_{u,t+1} - (1 - \psi_u) h_{u,t} - p_{u,t} s_{u,t} (1 - h_{u,t}) \big) \Big] \Big\}. \end{aligned} \tag{5.14}$$

The first-order conditions of the household's optimization problem follow as:

$$U_c(\cdot) = \lambda_t \tag{5.15}$$

$$-\kappa_{s_s,s}(s_{s,t})\lambda_t = \xi_{1,t}p_{s,t} \tag{5.16}$$

$$-\kappa_{s_u,u}(s_{u,t})\lambda_t = \xi_{2,t}p_{u,t} \tag{5.17}$$

$$\lambda_t = \beta E_t\Big\{\lambda_{t+1}(1 + r_{t+1} - \delta)\Big\} \tag{5.18}$$

$$\begin{aligned}\xi_{1,t} = \beta\Big\{&U_{h_s}(\cdot) - \lambda_{t+1}\big(w_{s,t+1}h_{s,t+1} + \kappa_s(s_{s,t+1})\big)\\ &+\xi_{1,t+1}\big((1-\psi_s) - p_{s,t+1}s_{s,t+1}\big)\Big\}\end{aligned} \tag{5.19}$$

$$\begin{aligned}\xi_{2,t} = \beta\Big\{&U_{h_u}(\cdot) - \lambda_{t+1}\big(w_{u,t+1}h_{u,t+1} + \kappa_u(s_{u,t+1})\big)\\ &+\xi_{2,t+1}\big((1-\psi_u) - p_{u,t+1}s_{u,t+1}\big)\Big\},\end{aligned} \tag{5.20}$$

where λ, ξ_1 and ξ_2 denote the Lagrange multiplier of the respective constraint.

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 factors of production, capital and labor, are bought at the interest rate r_t and the wage rate $w_{i,t}$, respectively. It should be noted that the wage is determined in a Nash bargaining procedure which will be described below. The assumption that the household owns and accumulates physical capital and that firms only decide over the use of capital in the production process refers to Cooley and Quadrini (1999) as well as Burda and Weder (2002). A slightly different approach is to assume that firms invest and accumulate physical capital (see Langot (1995)). By assuming a perfect capital market and under the assumption of market clearing both approaches lead to the same solution. The firm's decision problem is given by:

$$\max_{k_t, v_{i,t}} E_t \sum_{t=0}^{\infty} \beta^t \lambda_t \Pi_t \tag{5.21}$$

subject to

$$h_{s,t+1} = (1 - \psi_s) h_{s,t} + q_{s,t} v_{s,t} \tag{5.22}$$

$$h_{u,t+1} = (1 - \psi_u) h_{u,t} + q_{u,t} v_{u,t}, \tag{5.23}$$

where $\beta\lambda_t$ denotes the pricing kernel of the profit flow of the firm[2] which is denoted by Π_t, i.e.

$$\Pi_t = f(k_t, h_{s,t}, h_{u,t}, z_t) - \sum_{i=s,u} w_{i,t} h_{i,t} - r_t k_t - \sum_{i=s,u} a_i v_{i,t}. \tag{5.24}$$

Note that z_t describes a shock in technology which is assumed to follow a stationary stochastic process which is described by the following law of motion:

$$z_{t+1} = \omega z_t + \epsilon^z_{t+1}, \tag{5.25}$$

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

[2] As shown by Langot (1995), the pricing kernel is derived from the dynamic program of the firm which can be written as

$$\max_{k_t, v_{i,t}} E_0 \Big[\sum_{t=0}^{\infty} \tilde{\rho}_t \Pi_t \Big] = \max_{k_t, v_{i,t}} \sum_{t=0}^{\infty} \int \frac{\tilde{\rho}(x_t)}{\tilde{\rho}(x_0)} \Pi_t(x_t) dx_t.$$

The pricing kernel of a unit of flow profit at time t contingent to the state x_t, is the price of time 0 profit, i.e. $\int \frac{\tilde{\rho}(x_t)}{\tilde{\rho}_0} f(x_{t+1}|x_t) dx_t$. Furthermore, from the firm's optimality conditions on vacancy creation and the household's envelope condition with respect to $h_{i,t}$, gives the relation between the kernel pricing process and the Lagrange multiplier of the household's budget constraint, i.e.

$$\frac{\tilde{\rho}_{t+1}}{\tilde{\rho}_t} = \beta \frac{\lambda_{t+1}}{\lambda_t}.$$

See Langot (1995) p. 295 f. for further details. A slightly different approach is followed by Merz (1995) (cf. Merz (1995) p. 289). However, the results of Merz (1995) and Langot (1995) are equivalent if the pricing kernel in equation (5.21), $\tilde{\rho}_t$, is replaced by $\beta^t \lambda_t$. That means, that the firms employ the household's intertemporal valuation of assets.

Given the firm's profits as well as the constraints (5.23) and (5.24), the following Lagrange function of the firm's problem is derived

$$\max_{k_t, v_{i,t}} \mathcal{L}^F = E_t \Big\{ \sum_{t=0}^{\infty} \beta^t \Big[\lambda_t \Pi_t + \chi_{1,t} \big(h_{s,t+1} - (1-\psi_s) h_{s,t} - q_{s,t} v_{s,t} \big) + \chi_{2,t} \big(h_{u,t+1} - (1-\psi_u) h_{u,t} - q_{u,t} v_{u,t} \big) \Big] \Big\}, \tag{5.26}$$

where χ_1, χ_2 denote the Lagrange multipliers of the firm's constraints.

The respective first order conditions read as follows,

$$f_k(\cdot) = r_t \tag{5.27}$$

$$\chi_{1,t} = -\frac{\lambda_t a_s}{q_{s,t}} \tag{5.28}$$

$$\chi_{2,t} = -\frac{\lambda_t a_u}{q_{u,t}} \tag{5.29}$$

$$-\chi_{1,t} = \beta \Big\{ \lambda_{t+1} (f_{h_s,t+1}(\cdot) - w_{s,t+1}) - \chi_{1,t+1}(-1+\psi_s) \Big\} \tag{5.30}$$

$$-\chi_{2,t} = \beta \Big\{ \lambda_{t+1} \big(f_{h_u,t+1}(\cdot) - w_{u,t+1} \big) - \chi_{2,t+1}(-1+\psi_u) \Big\}. \tag{5.31}$$

Wage Setting and Inequality

The recent section is closely related to section 3.2 where the bargaining process was introduced. Again, the wage is negotiated according to a Nash bargaining[3] 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

[3] This bargaining approach is the standard one proposed by the literature. See, for example, Pissarides (2000), or Cahuc and Zylberberg (2004). A more detailed description of Nash bargaining can be found in Binmore, Rubinstein, and Wolinsky (1986).

of a productive job between firms and workers.[4] For a worker of type i who matches to a firm, the value of a job is given by the real wage $w_{i,t}$ less the 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.

The net surpluses of the household and the firm are derived by applying the envelope condition to the firm's and household's optimization problems, as given by the respective Lagrange functions (see equations (5.14) and (5.26)).[5]

The net surplus of the household is given by

$$\Omega_i^H = w_{i,t} + \kappa_i(s_{i,t}) - U_{h_{i,t}}(c_t, h_{i,t}) + \frac{\kappa_{s_{i},i}(s_{i,t})}{p_{i,t}}(1 - \psi_i - p_{i,t}s_{i,t}).$$

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

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

The Nash bargaining criterion is given by

$$w_t = \text{argmax} \ \left(\Omega_i^H\right)^{\phi_i}\left(\Omega^F\right)^{1-\phi_i}, \tag{5.32}$$

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

[4] *"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) p. 15.

[5] The envelope condition is obtained by the time t derivation with respect to $h_{s,t}$ and $h_{u,t}$ of the Lagrange functions (equations (5.14), (5.26)).

$$w_{i,t} = \phi_i \left[f_{h_i}(k_t, h_{s,t}, h_{u,t}, z_t) + \sum_i a_i \theta_{i,t} \right] + (1 - \phi_i) \left[\frac{U_{h_{i,t}}(\cdot)}{\lambda_t} - \kappa_i(s_{i,t}) \right]. \quad (5.33)$$

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

$$\frac{w_h}{w_u} = \frac{\phi_h \left[f_{h_s}(\cdot) + a_s \theta_{h,t} \right] + (1 - \phi_s) \left[\frac{U_{h_s}(\cdot)}{\lambda} - \kappa_{s_s}(s_{h,t}) \right]}{\phi_s \left[f_{h_u}(\cdot) + a_u \theta_{u,t} \right] + (1 - \phi_u) \left[\frac{U_{h_u}(\cdot)}{\lambda} - \kappa_{s_u}(s_{u,t}) \right]}. \quad (5.34)$$

For comparison, if we were to consider a model with a perfect labor market, as in the previous chapter (see 4.27), wage inequality would be given by:

$$\frac{w_s}{w_u} = \frac{\gamma}{1 - \gamma} \left[\frac{A^{\varepsilon_h}}{A^{\varepsilon_u}} \right]^{\frac{\sigma - 1}{\sigma}} \left[\frac{h_s}{h_u} \right]^{-\frac{1}{\sigma}}. \quad (5.35)$$

Comparing equations (5.34) and (5.35), 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 percentage of the firm's surplus distributed to the workers. Furthermore, as can be seen easily, equations (5.34) and (5.35) coincide in the case when ϕ_i converges to 1 and when no costs of vacancy creation are assumed. Beside the fact that the worker's 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 worker's bargaining power ϕ_i.

5.3 Equilibrium Solution

According to Langot (1995) the symmetric general equilibrium solution is obtained as follows: first the optimal job search and vacancy creation behavior are computed, and the wage rate is determined within a Nash-bargaining framework. Second, market clearing conditions in the goods and capital markets are imposed. However, because the wage is not the price which clears, for example a Walrasian labor market, the solution to this problem is not a Pareto optima.[6] Because of 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.[7] An equilibrium of this economy is a set of variables

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

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

From the first-order conditions of households' maximization problem, given by equations (5.15)-(5.20), the following Euler equations are derived:

[6] Cf. Langot (1995) p. 297.
[7] Cf. Pissarides (2000) p. 7.

$$\beta E_t \Big\{ \frac{U_c(c_{t+1})}{U_c(c_t)}(1 + r_{t+1} - \delta) \Big\} = 1 \quad (5.36)$$

$$\begin{aligned} \beta E_t \Big\{ -U_{h_s}(h_{s,t}) + \lambda_{t+1}(w_{s,t+1}h_{s,t+1} + \kappa_s(s_{s,t+1})) + \\ \frac{\kappa_{h_s,s}(s_{s,t+1})}{p_{s,t+1}} \lambda_{t+1}(1 - \psi_s - p_{h,t+1}s_{s,t+1}) \Big\} - \\ \frac{\kappa_{h_s,s}(s_{s,t})\lambda_t}{p_{s,t}} = 0 \end{aligned} \quad (5.37)$$

$$\begin{aligned} \beta E_t \Big\{ -U_{h_u}(h_{u,t}) + \lambda_{t+1}(w_{u,t+1}h_{u,t+1} + \kappa_u(s_{u,t+1})) + \\ \frac{\kappa_{h_u,u}(s_{u,t+1})}{p_{u,t+1}} \lambda_{t+1}(1 - \psi_u - p_{u,t+1}s_{u,t+1}) \Big\} - \\ \frac{\kappa_{h_u,u}(s_{u,t})\lambda_t}{p_{u,t}} = 0. \end{aligned} \quad (5.38)$$

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

By rearranging the first-order conditions of the firm's decision problem given by equations (5.27)-(5.31), the following Euler equations are derived:

$$f_k(\cdot) - r_t = 0 \quad (5.39)$$

$$\frac{\lambda_t a_s}{\lambda_{t+1} q_{s,t}} - \beta E_t \Big\{ f_{h_s}(\cdot) - w_{s,t+1} + \frac{a_s}{q_{s,t+1}}(1 - \psi_s) \Big\} = 0 \quad (5.40)$$

$$\frac{\lambda_t a_u}{\lambda_{t+1} q_{u,t}} - \beta E_t \Big\{ f_{h_u}(\cdot) - w_{u,t+1} + \frac{a_u}{q_{u,t+1}}(1 - \psi_u) \Big\} = 0. \quad (5.41)$$

The equilibrium solution is specified by the household's and the firm's Euler equations (5.36)-(5.41), as well as equations (5.1), (5.2), (5.3), (5.4), (5.5), (5.6), (5.7), (5.8), (5.11), (5.25), (5.33) and the aggregate resource constraint, which is given by

$$c_t + I_t + \kappa_s(s_{s,t}) + \kappa_u(s_{u,t}) + a_s v_{s,t} + a_u v_{u,t} = y_t. \quad (5.42)$$

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

$$U(c_t, h_{s,t}, h_{u,t}) = \frac{c_t^{1-\Phi}}{1-\Phi} - \frac{h_{s,t}^{1+\nu_s}}{1+\nu_s} - \frac{h_{u,t}^{1+\nu_u}}{1+\nu_u} \tag{5.43}$$

$$\kappa_s(s_{s,t}) = \bar{\kappa}_s s_{s,t}^{\mu} \tag{5.44}$$

$$\kappa_u(s_{u,t}) = \bar{\kappa}_u s_{u,t}^{\mu}. \tag{5.45}$$

The aggregate production function was already introduced in chapter 4.3 by equation (4.21):

$$f(\cdot) = z_t \left(\alpha \Big(\gamma (z_t^{\varepsilon_s} h_{s,t})^{\sigma_1} + (1-\gamma)(z_t^{\varepsilon_u} h_{u,t})^{\sigma_1} \Big)^{\frac{\sigma_2}{\sigma_1}} + (1-\alpha) k_t^{\sigma_2} \right)^{\frac{1}{\sigma_2}}. \tag{5.46}$$

In order to study the effects of skill-augmenting technology shocks, we rewrite (5.46) to[8]

$$f(\cdot) = z_t \left(\alpha \Big(\gamma (\breve{z}_t^{\varepsilon_s} h_{s,t})^{\sigma_1} + (1-\gamma)(\tilde{z}_t^{\varepsilon_u} h_{u,t})_1^{\sigma} \Big)^{\frac{\sigma_2}{\sigma_1}} + (1-\alpha) k_t^{\sigma_2} \right)^{\frac{1}{\sigma_2}} \tag{5.47}$$

where we assume that the two skill-augmenting technology shocks, $\breve{z}_t, \tilde{z}_t$ and the neutral advance in technology, z_t, follow uncorrelated stationary stochastic processes.

The matching technologies are specified by analogy with Merz (1995) or Pierrard and Sneessens (2003)

$$M_{s,t} = v_{s,t}^{\rho_1} (s_{s,t} \cdot u_{s,t})^{(1-\rho_1)} \tag{5.48}$$

$$M_{u,t} = v_{u,t}^{\rho_2} (s_{u,t} \cdot u_{u,t})^{(1-\rho_2)}, \tag{5.49}$$

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

[8] See also equation 4.22.

5.4 Numerical Analysis

5.4.1 Calibration

The calibration is chosen in accordance with the literature. The parameters of the matching technologies as well as the search costs are chosen in accordance with 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[9] 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%.The destruction rates used for the calibration are chosen in accordance to the latter observation.

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 2.1, 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 analogously to Heckman, Lochner, and Taber (1998), who estimate an elasticity of 1.4. Furthermore, we follow their empirical results of an 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, Rubart, and Semmler (2004). The values of the worker's bargaining power ϕ_i

[9] This statistic for the manufacturing sector is based on job flow data taken from the Bundesagentur für Arbeit (WZ93/BA).

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

Table 5.1. Parameter settings

$\bar{h}_s$	$\bar{h}_u$	$\bar{\tilde{u}}_s$	$\bar{\tilde{u}}_h$	$\bar{z}, \bar{\tilde{z}}, \bar{\check{z}}$	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	$\omega_z, \omega_{\check{z}}, \omega_{\tilde{z}}$	$\epsilon_z, \epsilon_{\check{z}}, \epsilon_{\tilde{z}}$
0.025	0.5	0.5	1.5	1.0	0.95	0.007

As described in chapter 4.4, the steady state of the deterministic part of the model is computed numerically by a Newton-Raphson method provided by DYNARE. The obtained impulse response functions rely on a first order approximation of the stochastic model around its steady state.

In advance of the following discussion, only one calibration setup is considered. Although different calibration setups for U.S. and European countries should be discussed, the model results are robust due to parameter variations. This means that, by varying the following parameters and variables, i.e. the ratio of skilled to unskilled workers, job creation and destruction rates, which can be seen as the most important differences, no qualitative differences in the results are found.

Therefore, only one model setup, which is based on empirical evidence for U.S. and European economies is studied, and compared to the respective time series data.

5.4.2 Impulse-Response Analysis

As in chapter 4.4, the effects of unanticipated and asymmetrical technological advances are examined under the assumption of labor market imperfections due to search and matching frictions.[10] Technological asymmetries arise due to three types of technology, where it is distinguished between neutral, skill- and low-skill-biased technological change. The particular focus of the examination lies on the effects technological changes have on the employment pattern of the different skill groups.

Figure 5.1 below presents the obtained responses of output due to unanticipated shocks in the three types of technology.

[10] The results of a model with symmetric technology shocks are presented in appendix A.

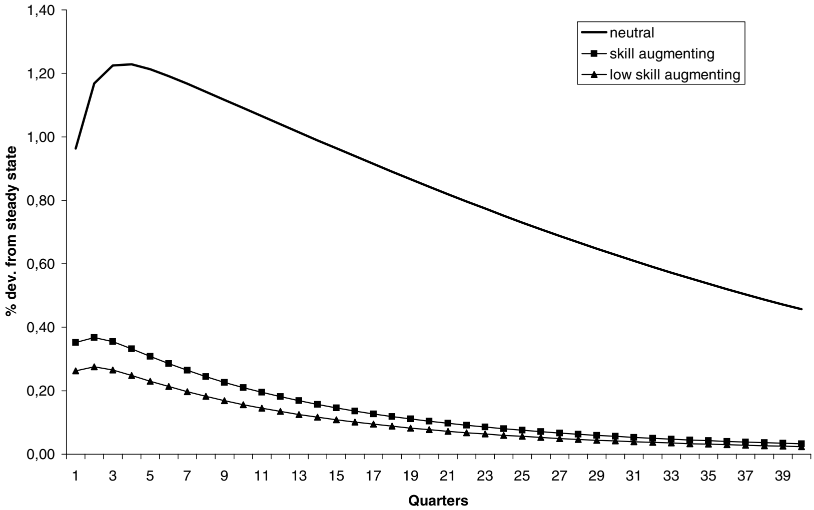

Fig. 5.1. Output responses of asymmetrical technology shocks

It is shown by figure 5.1 that the impulse responses of output of the model with search frictions exhibit a significant delayed, or hump-shaped pattern. This result is not reproduced by the RBC-type model (see, for example, figure 4.1). The observed pattern is particularly caused by the fact that an increased number of job openings cannot be filled immediately, as opposed to a model with perfect labor markets. Secondly, due to the assumed substitution elasticity between both types of labor and between labor and physical capital, the adjustment process is delayed, too. In addition, the results presented in figure 5.1 show that the greatest response of output is caused by neutral technological change, rather than skill-biased technological progress, as in the model of the previous chapter.

As shown by figure 5.2, two types of technology shocks reproduce a result indicated by the VAR analysis of chapter 2.3.2, i.e. a delayed response of the relative employment position. This effect is obtained for neutral and skill-biased technology shocks. The adjustment path of the neutral shock is explained by the greater availability and lower search costs of low-skilled workers. In addition, the general increase in productivity leads the demand for the group of skilled workers to increase faster. For skill- and low-skill-augmenting productivity shocks, we observe that the first shock leads to the expected pattern explained by the skill bias, i.e. it leads to a persistent increase in the relative employment position, which is, for example found for U.S. data (see figure section 2). This effect still holds for firms' vacancy creating activities, see also figures 5.3 and 5.4 below.

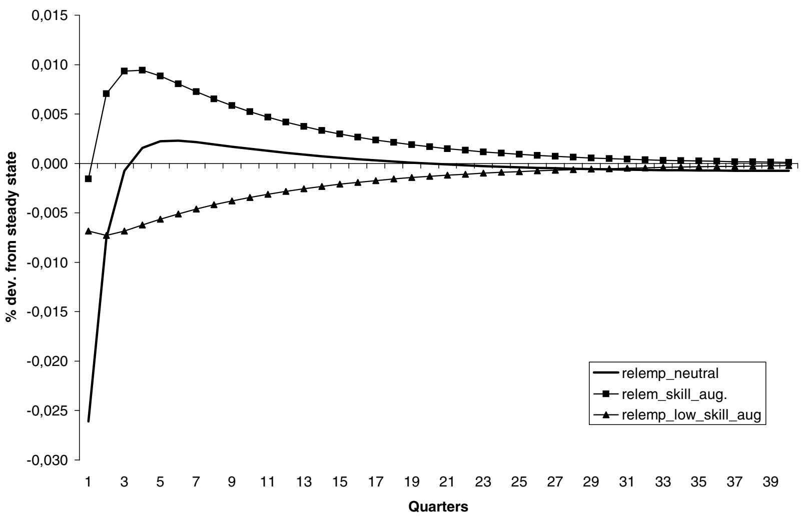

Fig. 5.2. Responses of relative employment

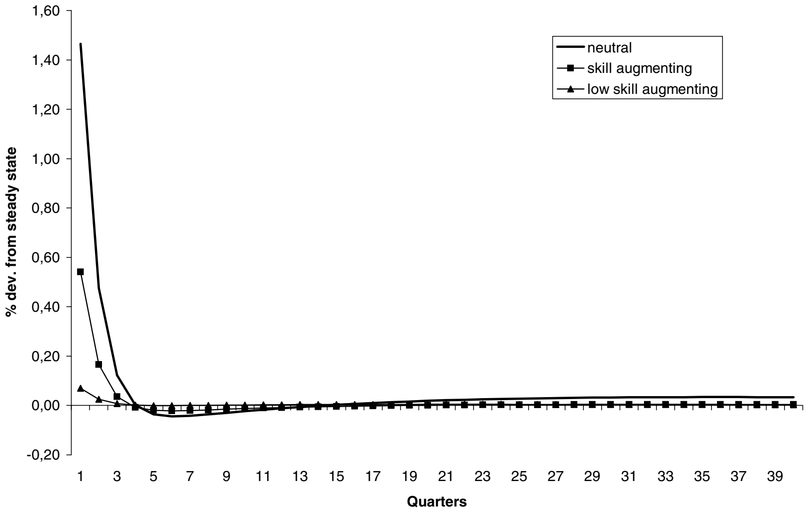

Fig. 5.3. Vacancy creation for skilled workers

As shown by figure 5.3 above, the highest increase of vacancy creation for skilled workers is due to a neutral or symmetrical productivity shock. As already shown by figure 5.1 the gain from this symmetric productivity shock, in terms of output (as well as profits), is big enough to increase the demand for both types of labor. For comparison, asymmetrical advances in productivity do not induce such an increase in profits which therefore leads to an increase in the creation of one type of vacancy and job, only. The effect described above still holds for the response of vacancy creation for low-skilled workers (see figure 5.4 below).

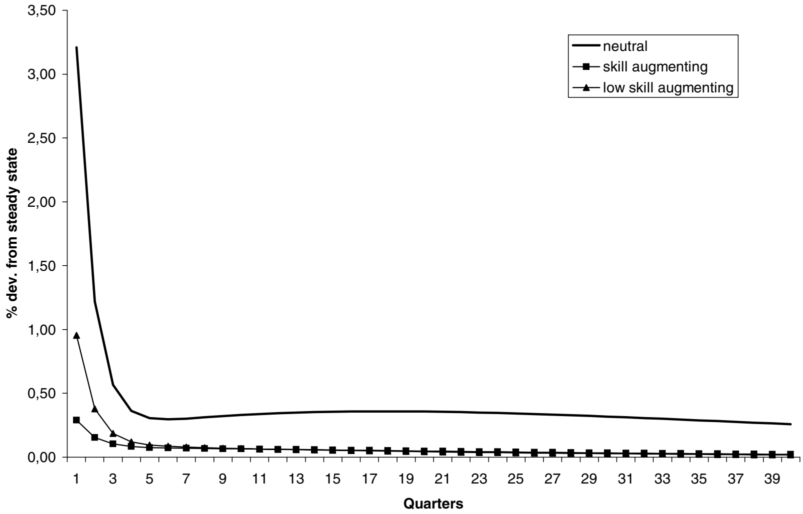

Fig. 5.4. Vacancy creation for low-skilled workers

As can be seen by the response due to a neutral technology shock (in comparison to the solid lines of figures 5.3 and 5.4), the vacancy creation for low-skilled jobs exceeds creation for skilled jobs by a factor of two. This pattern refers amongst others to the lower costs of vacancy creation, which are half of that for skilled workers. The reaction of the wage spread due to the asymmetrical technological shocks is presented in figure 5.5 below.

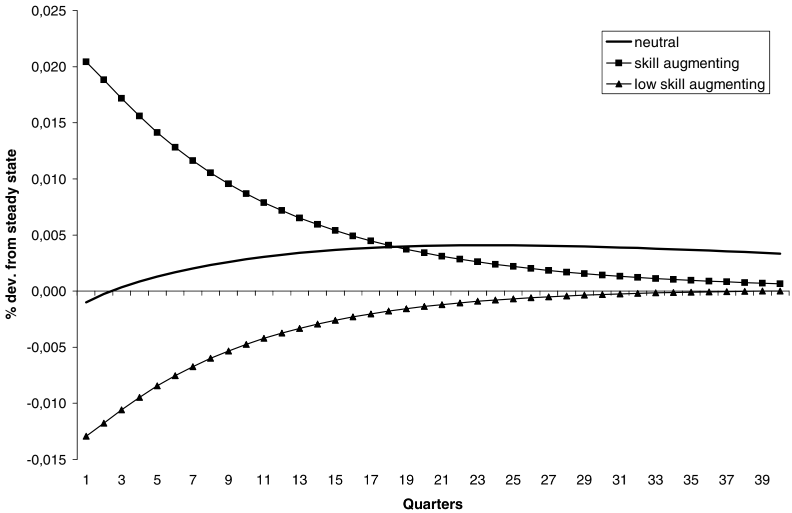

Fig. 5.5. Wage inequality

For the model with labor market frictions, we observe that a skill-biased technology shock leads to an immediate increase in the wage spread. For comparison, the response of the wage spread is about twice as high as in the model without labor market frictions (see figure 4.3). Furthermore, an increase in neutral technological change leads to a delayed increase in the wage spread, which reaches its maximum level after 20 quarters (five years). An increase in low-skill-augmenting technical change forces the wage spread, as expected, to respond negatively. In particular, the delayed and persistent increase of the wage spread after a neutral technology shock reproduces the empirical response of the wage spread after an orthogonal shock in labor productivity (see figures 2.8, to 2.10) found in the data for the U.S. and Germany.

The employment pattern due to technological advances of low-skilled workers is described by figure 5.6 below.

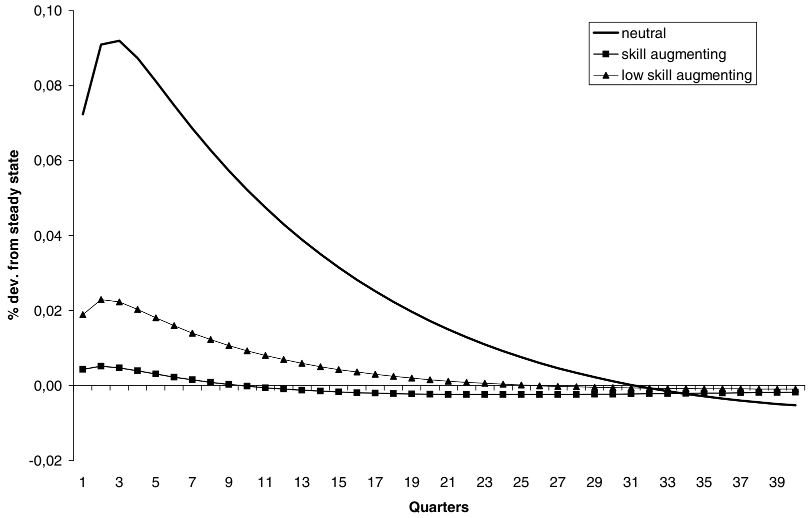

Fig. 5.6. Responses of low-skilled employment

When the behavior of vacancy creation was considered (see figure 5.4 above) the highest increase in employment of low skilled workers is caused by a neutral productivity shock. Due to the symmetrical effect, this kind of technological advance leads to an overall increase of the firm's (expected) profits above the costs of vacancy creation. Furthermore, unemployed workers' valuation of work exceeds the value of leisure, which induces a greater search efforts. All in all, the resulting effect is an overall increase in general employment and employment of low-skilled workers. Furthermore, the results of figure 5.6 indicate, in contrast to the RBC-type model, the effect of increasing unemployment of low skilled workers due to skill-biased technological change. In comparison to the RBC-type model of the previous chapter, in this model an increase in skill-biased technology leads to a rather low response of low-skilled employment; in particular, the response turns slightly negative after two years.

Besides the response of the variables to technological advances, in the next step the question is raised whether the model is able to reproduce correlations at business cycle frequencies. The obtained results from the model's simulation are reported in table 5.2 below.

Table 5.2. Business cycle properties of the model with search frictions

	Relative	Correlation of Simulated Variables								
	Volatility	y	c	i	n_s	n_u	n_s/n_u	w_s	w_u	w_s/w_u
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

In the case of the U.S. the model reproduces a positive correlation between output and skilled workers and the respective wages. However, the magnitudes of the obtained coefficients are too high in comparison to the data. Furthermore, we obtain a positive correlation between output and wage inequality and a negative one between output and relative employment. Both correlation are neither found for German or

U.S. time series. All in all, the ability of the model to reproduce some facts of the business cycle is mixed.

However, when one concentrates on dynamic correlations, as presented in table 5.3 below, one observes that the search model is able to reproduce the correlation of the wage spread and, in particular, the correlation between output and relative employment found for the German data.

Table 5.3. 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
Lindquist (2004)	-0.07	0.06	0.07	-/-	0.18
	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
Lindquist (2004)	0.19	0.10	0.03	-/-	-0.19

As reported in table 5.3, wage inequality and relative employment display a significant delayed pattern. This means the correlation coefficients in turn follow the business cycle, which can be seen by the increase in the correlation coefficients. For wage inequality they turn positive after one and two quarters, respectively. This delayed pattern is observed for Germany only where the coefficients increase up to period t+3. Although the search model does not reproduce the negative correlation of the wage spread, the output-inequality correlation at periods t+2 up to t+4 is matched quite well for both countries. By comparing the empirical correlations of relative employment with their simulated counterparts, one has to state that the search model replicates the findings for the German economy quite well. Whereas the findings of the U.S. are not replicated by both models. In the latter case, the model by Lindquist (2004), which assumes capital skill complementarity, provides a better reproduction of the U.S. data.

5.5 Discussion

The recent chapter presented a baseline stochastic dynamic general equilibrium model with labor market frictions and asymmetric technological change. In comparison to the RBC-type model of the previous chapter, a framework was developed in which it is possible to discuss the effects of technological advances on the employment pattern of different skill groups under the existence of equilibrium unemployment and an important labor market institution: wage bargaining.

In particular we have shown that neutral technological advances lead to the most positive response of economic activity as well as of job creation and employment. In particular, within this framework are able to reproduce the empirical finding (see e.g. Puhani (2005)) that skill biased technology shocks lead to an increase in low-skilled unemployment (see figure 5.6), a result that could not be reproduced by the RBC-type model with the assumption of perfect labor markets (see chapter 4.4, figure 4.4).

Although the capability of the analyzed model to reproduce business cycle facts has to be improved, we are able to derive important insights concerning the transmission process of the effects of technological change on employment and wages. This means that, within the recent framework, the creation of jobs and the pattern of employment which are derived from the agent's optimization problems were able to be studied. In addition, because of the labor market frictions, delayed or hump-shaped responses of important variables, such as output, wage inequality, and relative employment, were derived. The latter results provide, furthermore, an explanation of the empirical facts. Because of the costly and time consuming process of creating productive jobs, output and employment are not able to adjust immediately after the occurrence of technological advances. In comparison, such results were not found in the baseline general equilibrium framework without market frictions of chapter 4.

In addition, the recent model version is still characterized by a rather flexible wage setting mechanism; for example, employees are allowed to negotiate a new wage every period. However, continental European labor markets are characterized by rather rigid wage structure. In addition, institutions such as employment protection mechanisms, which also characterize central European labor markets, are not taken into account. Therefore, the framework developed in this chapter will be used to discus the effects of asymmetric technology shocks under wage rigidities and labor market institutions in the following chapter.

6

Extensions

It is probably fair to say that the representative-agent abstraction is viewed with suspicion by many labor economists. After all, heterogeneity has been an essential element of much of their work, and they find it necessary to include both observed and unobserved heterogeneity in their models in order to explain the observations
(F. Kydland (1984))

6.1 Labor Market Policies

In the preceding chapter, the effects of skill-biased technology change on the employment pattern of different groups of workers have been discussed within a dynamic general equilibrium framework under the assumption of search and matching frictions on the labor market. However, the latter framework shows some deficiencies which hamper a discussion of the effects of labor market policies and labor market institutions. Therefore, in this chapter the model discussed in chapter 5 is extended by two important labor market policies: minimum wages for low-skilled workers and employment protection mechanisms. In particular, the assumption of minimum wage rules allows us to consider another kind of wage rigidity. As we will show below this wage rule leads to a rigidity of relative wages which prevents the adjustment of the employment of different groups of workers. Within these frameworks we study and discuss the effects of technological change on employment and wages of different types of workers. Furthermore, we analyze the question of whether the above mentioned policies affect the long-run equilibrium of the economy.

A survey of the analysis of rigid wages is based on the findings of Shimer (2004), Hall (2003, 2005b) as well as Pierrard and Sneessens (2003, 2004) who show that wage rules which keeps wages from falling below a certain amount improve the performance of a search and matching framework to account for key facts of the business cycle. However, the studies cited above assume (except Pierrard and Sneessens (2003, 2004)) a wage rigidity that keeps wages fixed for several periods of time. As mentioned above, when minimum wages are considered, we either can assume that wages are prevented to fall below a certain threshold of, if different groups of workers are considered, that the wage distribution is compressed. In this thesis we follow the latter approach and assume a fixed wage distribution. In particular, this assumption accounts for the observation of rather fixed wages at the lower tail of the wage distribution, i.e. for the wages earned by low-skilled workers. In addition, this assumption accounts for the small increase in wage inequality in continental European countries (see table 2.1). Furthermore, the assumption of a minimum wage rule for low-skilled worker accounts for possible effects of policies demanded by some political parties in continental Europe who want to introduce "fair" wage setting mechanisms in order to reduce income inequality.

Employment protection mechanisms are already introduced in section 2.2 of this thesis. In general, such mechanisms can be introduced by assuming firing costs which influence the decisions of the firms when closing a job. This extension is primary based on the work by Saint-

Paul (1996), Kohns (2000) and Delacroix (2003). That employment protection legislation might influence the relative employment ratio was already described figure 2.6. There, it was shown that higher employment protection is related with a higher relative employment ratio. In order to model employment protection mechanisms, we assume that firms have to pay a “firing tax” to the government when they attempt to eliminate a job. Then, the government pays a lump-sum transfer to unemployed workers. This transfer payment can be interpreted as an additional unemployment benefit which increases the worker’s outside option and possibly prevents workers to search for a new job.

6.2 Employment Effects of Minimum Wages

As mentioned above, the importance of wage stickiness on employment fluctuations is described in recent studies by Hall (2003, 2005a,b). However, most studies concentrate almost exclusively on homogeneous labor and on sticky wages in the time dimension, i.e. there it is assumed that wages are fixed for several periods of time. Therefore, the assumption of minimum wage rules offers another perspective on wage stickiness. In particular, due to the collective bargaining mechanisms and the high bargaining coverage in continental European countries (see, for example, tables 2.1 and 2.3) the rigidity of relative wages is obvious.

By following the approaches of Pierrard and Sneessens (2003, 2004) we introduce a wage indexation scheme into the model. This means that wages for low-skilled workers are set as a constant fraction of the skilled workers’ wage.

As already mentioned, the analysis of minimum wages is based on the model outlined in chapters 5.2 and 5.3 in which the wage equation

(5.33) for low-skilled workers is replaced by the following condition:

$$w_u = \varrho w_s, \tag{6.1}$$

i.e. the wages paid to low skilled workers are determined as a given fraction, $\varrho \in [0,1]$ of wages bargained by skilled workers. The calibration and parameter setting of the model is analogous to chapter 5.4.[1] Concerning the wages of low-skilled workers, we assume $\varrho = 0.4$, i.e. low skilled workers earn 40% of the wage of skilled workers. This measure coincides with the actual German unemployment insurance payments as reported in table 2.4. Unfortunately, when calibrating the job destruction rates in accordance with the empirical facts, the solution of the model yields imaginary eigenvalues which lead to overshooting and cyclical reactions of the obtained impulse-response functions. By assuming higher, but unrealistic, job destruction rates, i.e. $\psi_s = 0.01$, $\psi_u = 0.04$, we can avoid this problem.[2]

[1] See table 5.1 for the parameter settings.

[2] The weighted average of the calibrated job destruction rate is 0.034, about twice as high than reported for the U.S. and three times higher as reported for Germany (see Ridder and van den Berg (2003)).

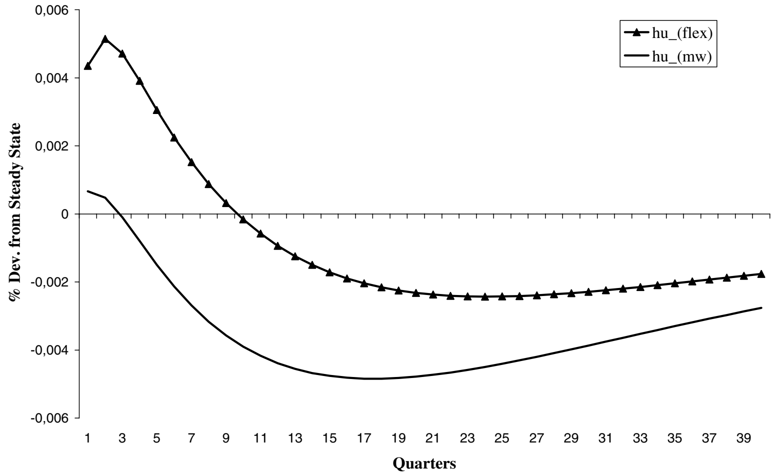

Fig. 6.1. Low-skilled employment after skill-biased technology shock

As, for example, described by Puhani (2005), skill-biased technology shocks account significantly for the rise in the observed unemployment pattern of German economy during the 1990's. In referring to the results of chapter 5.4, a more standard model is incapable of reproducing a persistent decline in low-skilled employment. However, under the assumption of rigid relative wages, a skill-biased technology shock reduces the response of the demand for low skilled workers by factor five (solid line, figure 6.1, above). In addition, there is no truly positive impact on the demand for low-skilled labor, whereas under the assumption of flexible wage bargaining schemes a small positive increase in the demand for low skilled labor persists for two and a half years.

Complementary to the results shown in figure 6.1, a skill-biased technology shock leads to a persistent increase in relative employment (figure 6.2, triangles).

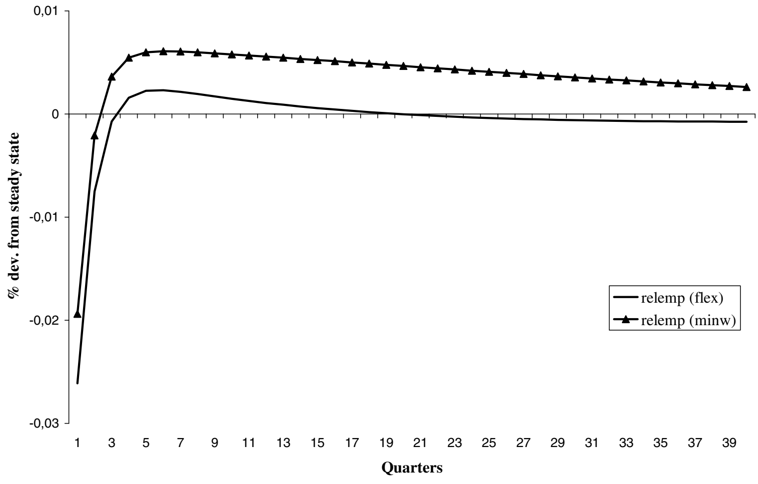

Fig. 6.2. Relative employment after skill-biased shock

In any case, the employment position of low-skilled workers worsen when rigid relative wages are taken into account. This can also be seen by the effects of a neutral and low-skill augmenting productivity shock (figure 6.3).

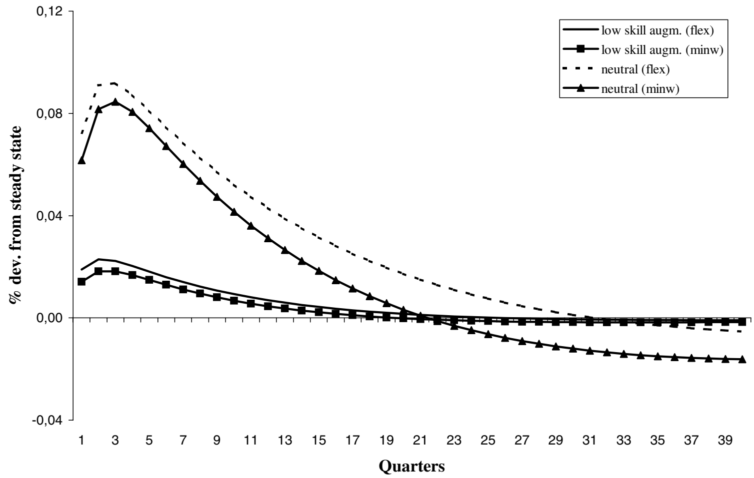

Fig. 6.3. Low-skilled employment, neutral and low-skill augmenting technology shock.

In line with the basic search model, the highest increase in labor demand for low-skilled workers is caused by a neutral productivity shock which leads to an overall increase in labor productivity. By introducing minimum wages, the persistence of this positive effect is reduced for about 10 quarters (2.5 years) in comparison to the basic search model. Concerning the persistency of an increase in low-skill-biased technology, no significant difference to the basic search model is found.

Table 6.1. Business cycle properties of the model

	Relative	Correlation of Simulated Variables					
	Volatility	y	c	i	h_s	h_u	w_s
y	—	1.00	0.77	0.90	0.86	0.63	0.77
c	0.64		1.00	0.41	0.63	0.06	0.49
i	0.69			1.00	0.81	0.84	0.73
h_s	0.001				1.00	0.41	0.40
h_u	0.05					1.00	0.62
w_s	0.51						1.00
w_u	0.20						—

In comparison to the previous models, the obtained time-t correlations can partly be improved, yet the empirical correlations concerning wages and employment are not replicated. However, the observed volatility of wages coincides with the empirical findings for the German data.

Although the introduction of minimum wages increases the magnitude of the correlation between relative employment and output, the delayed structure, i.e. an increase in the observed correlation over time, still holds. The increased magnitude of the obtained correlation coefficients is explained by the higher correlation between output and employment of skilled workers.

Table 6.2. Dynamic correlations

	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 (flex. wages)	-0.11	-0.07	0.06	0.10	0.08
Search (min. wages)	0.46	0.51	0.62	0.65	0.61

In addition to the question of whether the model is able to replicate the business cycle properties of the data, it is important to know if rigid relative wages influence the economy in the long-run. This will be done by analyzing whether the steady state levels of employment are determined by policy or technological parameters. In section 6.6 we show that the steady state employment level of low-skilled workers is rather invariant with respect to changes in the elasticity of substitution between both types of workers (figure 6.18). However, as the ratio of the minimum wage rule increases, the employment level of low-skilled workers decreases significantly. On the other hand, the employment level of skilled workers is rather invariant over a broad range of parameter values. However, if the minimum wage rule exceeds a certain threshold ($\varrho \approx$70%), a significant decline in the employment level of skilled workers is observed which leads further, due to income losses, a decrease in household's welfare.

6.3 Employment Protection Legislation

As already mentioned, labor market institutions are, in general, not characterized by the wage setting mechanism alone. Important institutional arrangements concern employment legislation and benefit payments such as unemployment insurance or assistance. In general, employment legislating policies concern employment protection policies such as dismissal protection. In order to analyze the effects of such policies we can introduce firing costs into the model. In general, firing costs can be classified into severance payments and firing taxes. Severance payments can be seen as a transfer from the firms to the workers and depend proportionally on the wage. Because severance payments are determined in an efficient contract or bargaining process, they influence equilibrium wages but not equilibrium unemployment.[3] Therefore, by following Delacroix (2003) the subsequent analysis concentrates on firing taxes only. The main difference to the model of chapter 5 is, that when firms attempt to eliminate a job, they have to pay an amount of b per eliminated job to an agency which distributes the total amount between unemployed workers of both types. This leads on the one hand to a reduced job creation for low-skilled workers because of the lower productivity and, on the other hand, to an increased reservation wage which hinders job search activities.

Based on Bentolila and Bertola (1990) Hopenhayn and Rogerson (1993), Saint-Paul (1996), Kohns (2000, 2002) and Delacroix (2003), we extend the model of the previous chapter by introducing firing costs and a simple government rule of unemployment assistance payments. In addition, the structure of unemployment assistance refers to Burda and

[3] Cf. Delacroix (2003) p. 651.

Weder (2002). As in the previous section, we focus on the effects of firing costs on employment and wages of the respective skill group under the presence of different types of technological progress. Furthermore, the impact of this kind of labor market policy on the long-run equilibrium of this model economy is examined.

6.3.1 A Revision of the Household's and the Firm's Problem

As in the previous chapters, we assume a representative household with a large number of inhabitants which is normalized to one. The household chooses consumption, c_t, and the search intensities, $s_{i,t}, i = s, u$ of the respective skill group in order to maximize the present discounted value of its 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 household's maximization problem reads as follows:

$$U_t = \max_{c_t, s_{i,t}} \sum_{t=0}^{\infty} \beta^t U(c_t, h_{s,t}, h_{u,t}) \tag{6.2}$$

subject to

$$c_t + I_t + \sum_{i=s,u} \kappa_i(s_{i,t})(1 - h_{i,t}) = \sum_{i=s,u} w_{i,t}h_{i,t} + \sum_{i=s,u} \tau_i^h(1 - h_{i,t}) + r_t k_t \tag{6.3}$$

$$k_{t+1} = (1 - \delta)k_t + I_t \tag{6.4}$$

$$h_{s,t+1} = (1 - \psi_s)h_{s,t} + p_{s,t}s_{s,t}(1 - h_{s,t}) \tag{6.5}$$

$$h_{u,t+1} = (1 - \psi_u)h_{u,t} + p_{u,t}s_{u,t}(1 - h_{u,t}), \tag{6.6}$$

where the expression $\tau_i(1 - h_{i,t})$ denotes the benefits obtained from an unemployed type i worker. From equations (6.2)-(6.6), the Lagrange function follows as

$$\begin{aligned}\max_{c_t, s_{i,t}} \mathcal{L}^{\mathcal{H}} = E_t\Big\{ \sum_{t=0}^{\infty} \beta^t \Big[& U(c_t, h_{s,t}, h_{u,t}) \\ & + \lambda_t\Big(\sum_{i=s,u} w_{i,t} h_{i,t} + \sum_{i=s,u} \tau_i^h (1 - h_{i,t}) + r_t k_t \\ & - c_t - I_t - \sum_{i=s,u} \kappa_i(s_{i,t})(1 - h_{i,t}) \Big) \\ & + \xi_{1,t}\big(h_{s,t+1} - (1-\psi_s) h_{s,t} - p_{s,t} s_{s,t} (1 - h_{s,t})\big) \\ & + \xi_{2,t}\big(h_{u,t+1} - (1-\psi_u) h_{u,t} - p_{u,t} s_{u,t} (1 - h_{u,t})\big) \Big] \Big\},\end{aligned} \tag{6.7}$$

from which the following first-order conditions are derived

$$U_c(\cdot) = \lambda_t \tag{6.8}$$

$$-\kappa_{s_s,s}(s_{s,t})\lambda_t = \xi_{1,t} p_{s,t} \tag{6.9}$$

$$-\kappa_{s_u,u}(s_{u,t})\lambda_t = \xi_{2,t} p_{u,t} \tag{6.10}$$

$$\lambda_t = \beta E_t\Big\{ \lambda_{t+1}(1 + r_{t+1} - \delta) \Big\} \tag{6.11}$$

$$\begin{aligned}\xi_{1,t} = \beta E_t\Big\{ & U_{h_s}(\cdot) - \lambda_{t+1}\big(w_{s,t+1} - \tau_s^h + \kappa_s(s_{s,t+1})\big) \\ & + \xi_{1,t+1}\big((1-\psi_s) - p_{s,t+1} s_{s,t+1}\big) \Big\}\end{aligned} \tag{6.12}$$

$$\begin{aligned}\xi_{2,t} = \beta E_t\Big\{ & U_{h_u}(\cdot) - \lambda_{t+1}\big(w_{u,t+1} - \tau_u^h + \kappa_u(s_{u,t+1})\big) \\ & + \xi_{2,t+1}\big((1-\psi_u) - p_{u,t+1} s_{u,t+1}\big) \Big\}.\end{aligned} \tag{6.13}$$

The firm's problem, which is described already by equations (5.21)-(5.24), is modified as follows. The firm's profits are defined as

$$\Pi = f(\cdot) - \sum_{i=s,u} w_{i,t} h_{i,t} - r_t k_t - \sum_{i=s,u} \tau_i^f \psi_i h_{i,t} - \sum_{i=s,u} a_i v_{i,t}, \tag{6.14}$$

where $\sum_{i=s,u} \tau_i^f \psi_i h_{i,t}$ denote the sum of firing costs the firm is faced with when eliminating a job. As in chapter 5.2, the firm has to solve the following optimization problem:

$$\max_{k_t, v_t} E_t \sum_{t=0}^{\infty} \beta^t \lambda_t \Pi_t, \tag{6.15}$$

subject to

$$h_{s,t+1} = (1 - \psi_h) h_{s,t} + q_{h,t} v_{h,t} \tag{6.16}$$

$$h_{s,t+1} = (1 - \psi_u) h_{u,t} + q_{u,t} v_{u,t}. \tag{6.17}$$

The Lagrangean function of the above problem reads as follows,

$$\begin{aligned} \max_{k_t, v_{i,t}} \mathcal{L}^F = E_t \Big\{ \sum_{t=0}^{\infty} \beta^t \Big[& \lambda_t \Pi_t \\ & + \chi_{1,t} \big(h_{s,t+1} - (1 - \psi_s) h_{s,t} - q_{s,t} v_{s,t} \big) \\ & + \chi_{2,t} \big(h_{u,t+1} - (1 - \psi_u) h_{u,t} - q_{u,t} v_{u,t} \big) \Big] \Big\}. \end{aligned} \tag{6.18}$$

The respective first-order conditions follow as,

$$f_k(\cdot) = r_t \tag{6.19}$$

$$\chi_{1,t} = -\frac{\lambda_t a_s}{q_{s,t}} \tag{6.20}$$

$$\chi_{2,t} = -\frac{\lambda_t a_u}{q_{u,t}} \tag{6.21}$$

$$\begin{aligned} -\chi_{1,t} = \beta E_t \Big\{ & \lambda_{t+1} (f_{h_s,t+1}(\cdot) - w_{s,t+1} - \tau_s^f \psi_s) \\ & - \chi_{1,t+1}(-1 + \psi_s) \Big\} \end{aligned} \tag{6.22}$$

$$\begin{aligned} -\chi_{2,t} = \beta E_t \Big\{ & \lambda_{t+1} \big(f_{h_u,t+1}(\cdot) - w_{u,t+1} - \tau_u^f \psi_u \big) \\ & - \chi_{2,t+1}(-1 + \psi_u) \Big\}. \end{aligned} \tag{6.23}$$

Furthermore, it is assumed that the total amount of the firing tax is equal to the amount of unemployment benefits, i.e. we assume a simple budget equation for the social security system:

$$\sum_{i=s,u} \tau^f \psi_i h_{i,t} = \sum_{i=s,u} \tau_i^h (1 - h_{i,t}). \tag{6.24}$$

Wages are set according to a Nash bargaining rule. In accordance to chapter 5.2 (see (5.33)), the bargained wage of a type i worker is given by

$$w_{i,t} = \phi_i \Big[f_{h_i}(\cdot) + \sum_{i=s,u} a_i \theta_{i,t} - \tau_i^f \psi_i \Big]$$
$$+ (1-\phi_i) \Big[\frac{u_{h_{i,t}}(\cdot)}{\lambda_t} - \kappa_i(s_{i,t}) + \tau_i^h \Big]. \qquad (6.25)$$

Please note that the modified wage equation differs from the basic one in two aspects. First, the firing costs reduce the worker's surplus by $\tau_i^f \psi_i$, but the benefit payments increase the worker's reservation wage by τ_i^h.

6.3.2 Equilibrium Solution

In accordance with chapter 5.3, an equilibrium of this economy is a set of variables

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

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

From the first-order conditions of households' maximization problem, given by equations (6.8)-(6.13), the following Euler equations are derived

$$\beta E_t \left\{ \frac{U_c(c_{t+1})}{U_c(c_t)}(1 + r_{t+1} - \delta) \right\} = 1 \quad (6.26)$$

$$\beta E_t \Big\{ -U_{h_s}(h_{s,t}) + \lambda_{t+1}(w_{s,t+1} - \tau_s^h + \kappa_s(s_{s,t+1})) + \frac{\kappa_{h_s,s}(s_{s,t+1})}{p_{s,t+1}} \lambda_{t+1}(1 - \psi_s - p_{h,t+1}s_{s,t+1}) \Big\} - \frac{\kappa_{h_s,s}(s_{s,t})\lambda_t}{p_{s,t}} = 0 \quad (6.27)$$

$$\beta E_t \Big\{ -U_{h_u}(h_{u,t}) + \lambda_{t+1}(w_{u,t+1} - \tau_u^h + \kappa_u(s_{u,t+1})) + \frac{\kappa_{h_u,u}(s_{u,t+1})}{p_{u,t+1}} \lambda_{t+1}(1 - \psi_u - p_{u,t+1}s_{u,t+1}) \Big\} - \frac{\kappa_{h_u,u}(s_{u,t})\lambda_t}{p_{u,t}} = 0. \quad (6.28)$$

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

By rearranging the first-order conditions of the firm's decision problem given by equations (6.19)-(6.23), the following Euler equations are derived

$$f_k(\cdot) - r_t = 0 \quad (6.29)$$

$$\frac{\lambda_t a_s}{\lambda_{t+1} q_{s,t}} - \beta E_t \Big\{ f_{h_s}(\cdot) - w_{s,t+1} - \tau_s^f + \frac{a_s}{q_{s,t+1}}(1 - \psi_s) \Big\} = 0 \quad (6.30)$$

$$\frac{\lambda_t a_u}{\lambda_{t+1} q_{u,t}} - \beta E_t \Big\{ f_{h_u}(\cdot) - w_{u,t+1} - \tau_u^f + \frac{a_u}{q_{u,t+1}}(1 - \psi_u) \Big\} = 0. \quad (6.31)$$

The equilibrium solution is specified by the household's and the firm's Euler equations (6.26)-(6.31), as well as equations (5.1), (5.2), (5.3), (5.4), (5.5), (5.6), (5.7), (5.8), (5.11), (5.47), (5.25), (6.25) and the aggregate resource constraint, which is given by

$$c_t + I_t + \kappa_s(s_{s,t}) + \kappa_u(s_{u,t}) + a_s v_{s,t} + a_u v_{u,t} = y_t. \quad (6.32)$$

Furthermore the budget rule of the benefit payments (6.24) has to be considered.

6.3.3 Calibration

The calibration and simulation of the model are analogous to the model discussed in chapter 5.[4] Because of the non-availability of proper data on firing costs, particular firing taxes, the following calibration of firing costs is assumed:

Table 6.3. Calibration of firing costs

	Scenario		
	I	II	III
h_s	$\tau_s^f = a_s$	$\tau_s^f = 2 \times a_s$	$\tau_s^f = \frac{1}{2} \times w_s$
h_u	$\tau_u^f = \tau_s^f$	$\tau_u^f = \tau_s^f$	$\tau_u^f = \frac{1}{2} \times w_u$

As described in table 6.3, three different scenarios of this firing tax are assumed. Scenarios I and II relate the level of the firing costs to the advertising costs of the firm; furthermore, it is assumed that the firing costs are equal for both types of workers. The difference between both scenarios is that in the second one, the firing cost exceeds the costs of hiring a skilled worker. The third scenario relates the firing costs to the wages, i.e. it is assumed that the firing cost is half of earned wages.

As mentioned above, the total sum of firing taxes are distributed as a lump-sum transfer to the workers. For simplicity, we assume that the amount of transfer payments is distributed equally across unemployed

[4] See table 5.1.

workers, i.e.

$$\tau_s^h(1-h_{s,t}) = \frac{1}{2} \times \sum_{i=s,u} \tau_i^f \psi_i h_{i,t}$$
$$\text{and} \tag{6.33}$$
$$\tau_u^h(1-h_{u,t}) = \frac{1}{2} \times \sum_{i=s,u} \tau_i^f \psi_i h_{i,t}.$$

As in the previous section, the analysis concentrates on the variables, output, relative employment and wages as well as on the employment pattern of low-skilled workers. Figure 6.4 shows the responses of output of different technology shocks and, furthermore, under the additional assumption of firing costs.

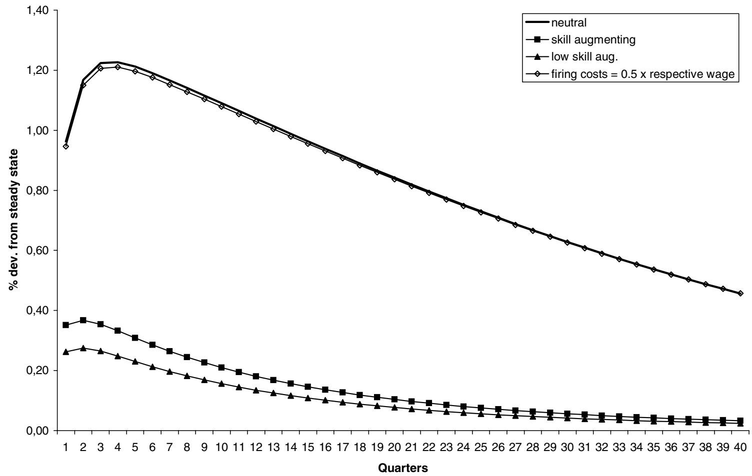

Fig. 6.4. Output response under firing costs

Because scenarios I and II, in which firing costs are related to the advertising costs of the firms, do not lead to different results (in comparison to the baseline search model) we concentrate on scenario III, only. There, similar to the results of section 5.4, the output response to the technology shocks is hump-shaped as found in the data, and, furthermore, the variation of the firing costs leads to slight quantitative changes in the obtained impulse responses only. In addition, the obtained results are close to the model studied in chapter 5. For the relative employment position as well as the wage spread the following results are obtained.

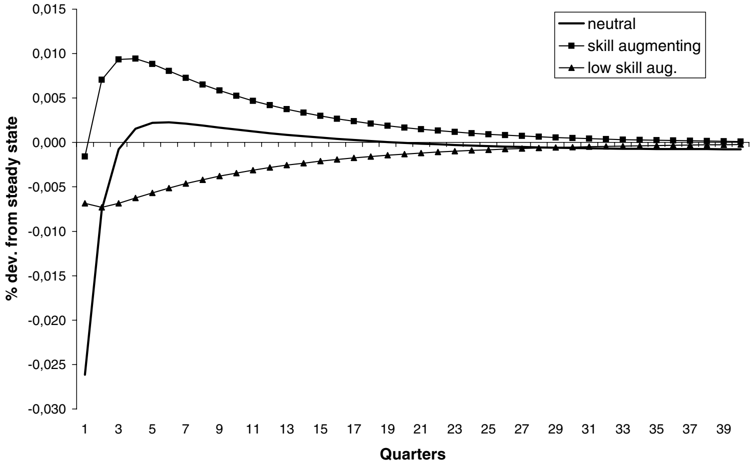

Fig. 6.5. Relative employment and firing costs.

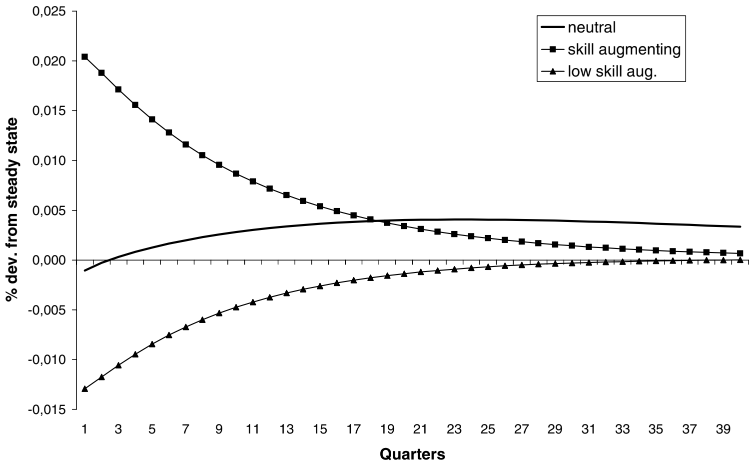

Fig. 6.6. Wage inequality and firing costs

As shown by figures 6.5 and 6.6 above, no qualitative differences to the general search model of the previous chapter are obtained. This effect arises because firing costs and benefit payments are incorporated into the household's and firm's decision problems, and furthermore, do not influence the wage adjustment process. That means that wages for both types of workers can adjust flexibly after the economy is hit by a technology shock. The comparison of the different scenarios in the employment pattern of low skilled workers yields an interesting result.

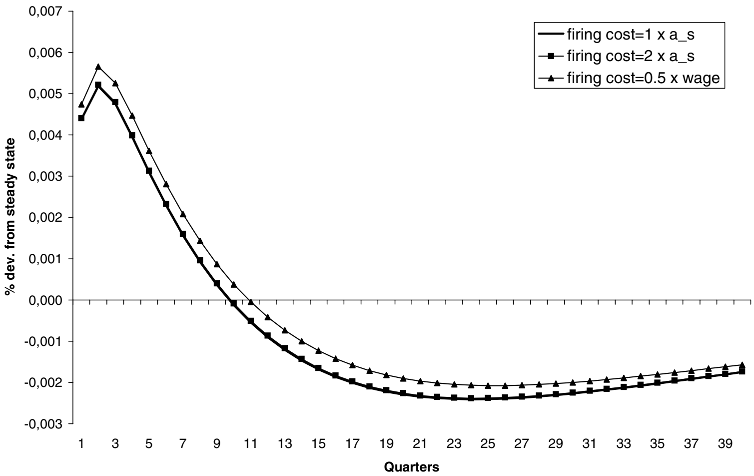

Fig. 6.7. Low skilled employment

Figure 6.7 above shows, that a higher firing cost increases employment of low-skilled workers, or, vice versa, reduces the destruction of low skilled jobs. However, this rather positive effect holds for about two quarters only, i.e. a significant increase in the employment status of low-skilled workers cannot be obtained by increasing job protection due to firing costs. As shown by the obtained impulse-response functions of the present model framework, firing costs do not have a negative impact on the employment status of this economy. The adjustment pattern is almost equivalent to the baseline model with search frictions discussed in chapter 5. In addition the recent approach replicates results obtained by Bentolila and Bertola (1990) who state, that *[...] firing costs do not have large effects on hiring decisions, nor do high firing costs reduce* *the average level of employment [...]* (cf. Bentolila and Bertola (1990) p. 382).

The business cycle properties of the model are reported below.

Table 6.4. Business cycle properties of the model with firing costs

	Relative Volatility	Correlation of Simulated Variables								
		y	c	i	n_s	n_u	n_s/n_u	w_s	w_u	w_s/w_u
y	—	1.00	0.63	0.88	0.75	0.79	-0.09	0.99	0.99	0.29
c	0.49		1.00	0.18	-0.02	0.06	0.01	0.68	0.67	0.28
i	0.78			1.00	0.96	0.98	-0.09	0.83	0.85	0.19
h_s	0.05				1.00	0.95	0.05	0.71	0.69	0.30
h_u	0.06					1.00	-0.18	0.71	0.69	0.30
h_s/h_u	0.01						1.00	0.03	-0.13	0.63
w_s	0.07							1.00	0.97	0.42
w_u	0.06								1.00	0.18
w_s/w_u	0.01									1.00

In comparison to the model without firing costs, the recent framework does not improve the model's ability to account for business cycle evidences. Furthermore, the observed volatility of wages and employment are too low in comparison to the empirical findings reported in table 4.2.

As in the previous chapter, one has to ask whether firing taxes affect the long-run equilibrium of this model economy. Figure 6.20 below shows the effects of various dismissal protection policies on the equilibrium employment level of low-skilled workers. As was to be expected from the impulse-response analysis, firing taxes or dismissal protection policies have no or rather minor effects on the equilibrium level of employment. However, in this economy the level of employment is determined by technological aspects such the elasticity of substitution between both types of workers, σ_1. In particular, if σ_1 increases, i.e. both types of workers become substitutes, the employment level of skilled workers decreases and vice versa.

6.4 Employment Protection and Minimum Wages

In this section we examine a combination of both approaches described in this chapter, i.e. we combine the model with firing costs (as outlined in section 6.3) with a minimum wage rule for low-skilled workers. For the calibration, we choose the following setup. The wages for low-skilled workers are set as $w_u = \varrho w_s$ with $\varrho = 0.4$ and the firing costs are assumed as 50% of the respective wage rate, i.e. $\tau_s^f = \frac{1}{2} \times w_u$ and $\tau_u^f = \frac{1}{2} \times w_u$.

As can be seen by the obtained impulse-response functions, the joint consideration of minimum wage rules and firing costs does not significantly change the results, in comparison to the model with minimum wages (see figures 6.1-6.3). However, the magnitude of the response of relative employment changes significantly in favor of the relative employment position of skilled workers (see figures 6.2 and 6.5).

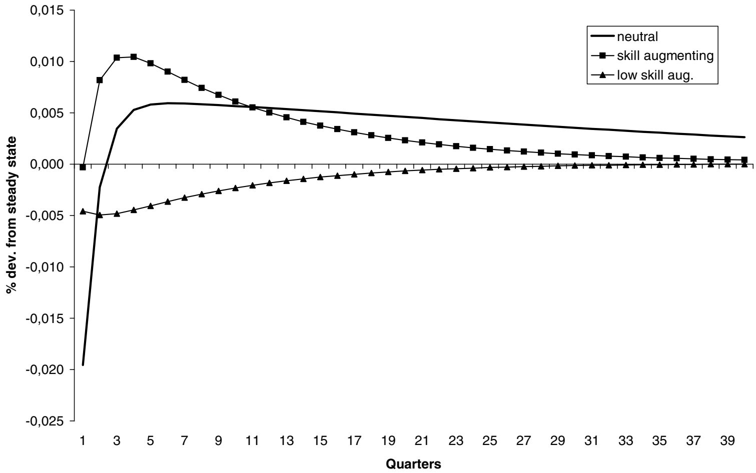

Fig. 6.8. Relative employment under firing costs and minimum wages

As shown by figure 6.9 below, the negative response of low-skilled employment is mostly driven by the inflexible wage adjustment of this group of workers. It is obvious that the magnitude and the behavior of the impulse-response of a skill-biased technology shown under firing costs alone (line with squares) shows a significant different behavior than the responses under the assumption of minimum wages.

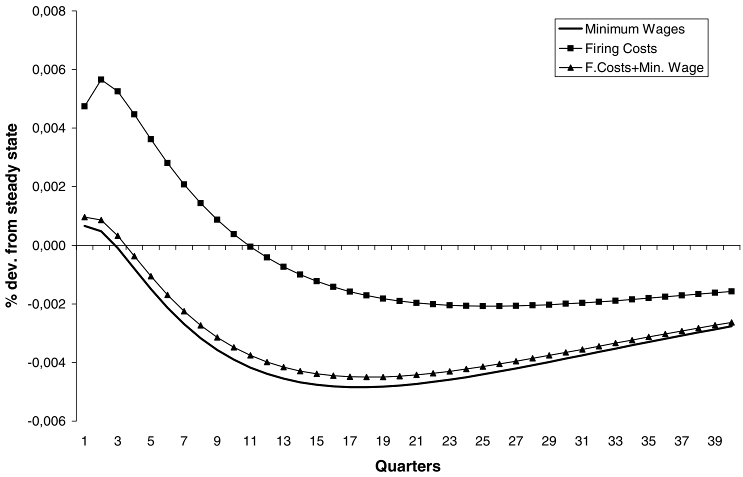

Fig. 6.9. Low-skilled employment under firing costs and minimum wages

Table 6.5. Properties of the model with firing costs and minimum wages

	Relative	Correlation of Simulated Variables						
	Volatility	y	c	i	h_s	h_u	h_s/h_u	w_s
y	—	1.00	0.59	0.88	0.64	0.31	0.79	0.77
c	0.48		1.00	0.18	-0.22	-0.55	0.62	0.67
i	0.79			1.00	0.92	0.72	0.60	0.82
h_s	0.05				1.00	0.89	0.47	0.58
h_u	0.03					1.00	0.12	0.21
h_s/h_u	0.02						1.00	0.82
w_s	0.10							1.00

Although the simulated correlations reported in table 6.5 above improve some results, the overall reproduction of business cycle facts is rather low. The main improvement is found for employment and wages. In comparison to the other models, the correlation coefficients are significantly lower than the ones reported in tables 4.3-6.1. In particular, under the further assumption of rigid relative wages we observe a positive correlation between output and relative employment. In addition the volatility of the wages of skilled workers is in line with the empirical findings for Germany (see table 4.2).

Table 6.6. A comparison of dynamic correlations

	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 (flex. wages)	-0.11	-0.07	0.06	0.10	0.08
Search (min. wages)	0.46	0.51	0.62	0.65	0.61
Search (min. wages+ firing costs)	0.75	0.79	0.88	0.87	0.80
Lindquist (2004)	0.19	0.10	0.03	-/-	-0.19

Again, although the correlation coefficients are overstated by the search model with firing costs and minimum wages, the delayed structure which is found for the German data is reproduced by the model. After comparing the correlation of the variables one has to conclude that the "simple" search model with heterogeneous labor generates the best fit of the empirical results found for the German data. On the other hand, the model by Lindquist (2004), in which a model with capital-skill complementarity is assumed, provides a sufficient explanation of the U.S. data. However, a RBC-type model with skill-biased technology shocks fails to provide a reasonable explanation of the data.

6.5 Sensitivity Analysis

Whether perfect labor markets are assumed, no negative response of the employment status of low skilled workers are obtained. The status of low skilled workers worsen, if labor market frictions are taken into account. In particular, rather no positive effect of an increase in productivity is found when wages for low skilled workers are indexed to the skilled workers wage. By comparing the U.S. and Europe, the latter assumption seems, unfortunately, to hold. Up to now, the examinations concentrate of specific calibrations of the models. However, a characterization how minimum wages and firing costs affect the decisions of the economic agents is still missing. The impacts of minimum wages and firing costs on the decisions of the individuals can be examined by a sensitivity analysis in which we compare the obtained impulse-response functions based on different parameter assumptions.

It becomes obvious that firing taxes have only low impacts on the vacancy creating and job search activities because the obtained impulse-responses do not differ significantly. Therefore, the employment of low skilled workers does not change. Figures 6.10 - 6.13 below show the obtained impulse response functions of a skill biased technology shock with respect to different calibrations of the firing tax.

As can be seen from figure 6.10 an increase in the firing tax up to 90% of the worker's wage only a slight decline in the employment position of low skilled workers is obtained.

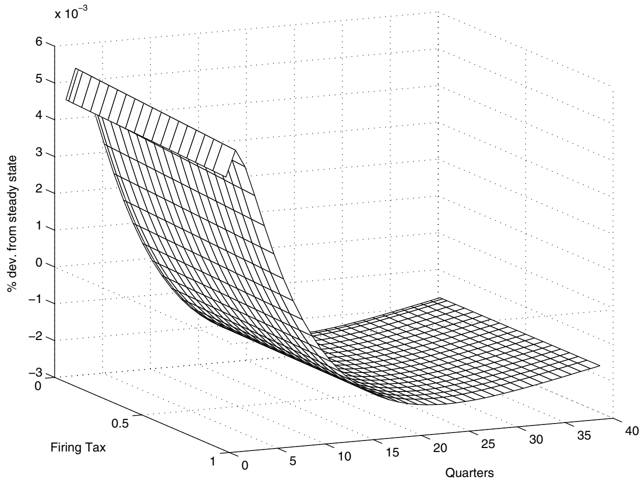

Fig. 6.10. Sensitivity analysis, employment h_u

The low impact of firing taxes on the employment position of low skilled workers is explained by the finding that job search and vacancy creating activities do not change significantly if the firing tax increases.

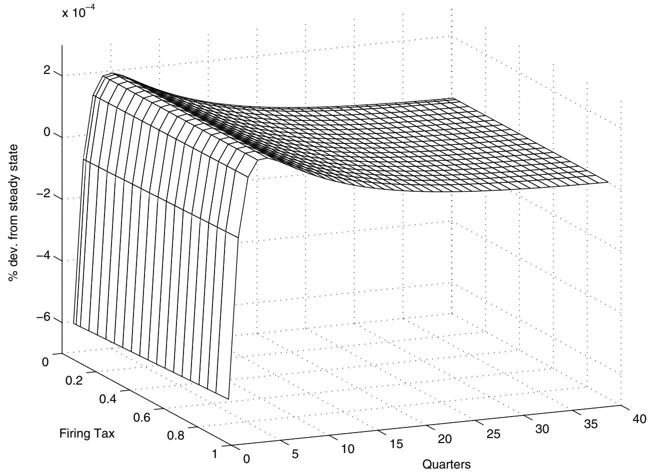

Fig. 6.11. Sensitivity analysis, search intensity s_u

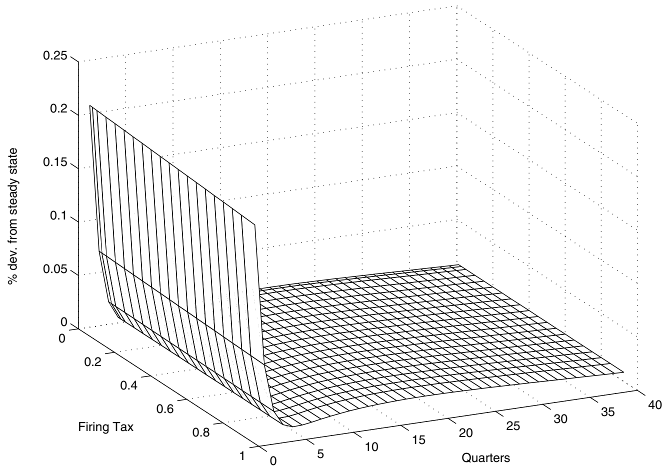

Fig. 6.12. Sensitivity analysis, vacancy creation v_u

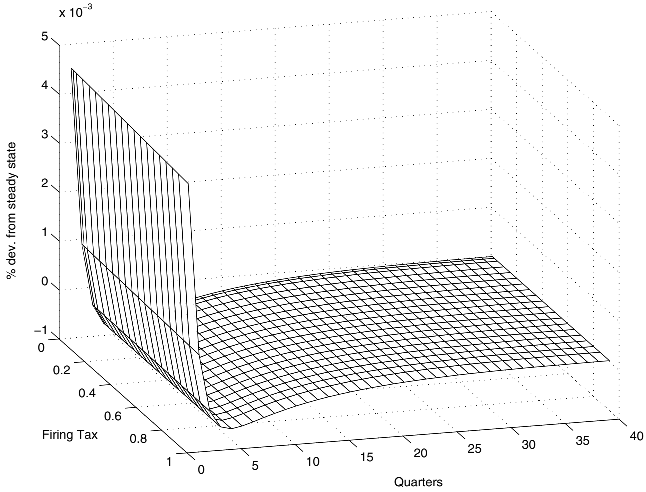

Fig. 6.13. Sensitivity analysis, job matches M_u

On the other hand, an increase in the minimum wage rate has significant effects on vacancy creating and job search activities. In a regime with rather low minimum wages, a skill-biased technology shock leads to an immediate, positive and persistent increase in job vacancies. Because the option value of becoming employed exceeds the gains from leisure (unemployment), low-skilled workers increase their job search activities. Both effects result in positive responses of job matches and employment. However, if the ratio of minimum wages exceeds 0.55 (0.6), vacancy creation declines rapidly.[5] In addition, because of the decline in the expected gain from becoming employed, low-skilled workers reduce their job search activities. This results in lower job matches and lower employment. By increasing the minimum wage rate to a value of 0.8 firms do not offer vacancies for low-skilled workers anymore. Then,

[5] Note that the implied (and reported) minimum wage rate for Germany is about 0.6 (see tables 2.3 and 2.4).

although job search activities of the workers increase because of the high minimum wage which is earned by the worker when he becomes employed, no positive response of employment and job matches is observed.

The sensitivity analysis shows that the positive effect of minimum wages, i.e. the increased job search activity of low-skilled workers, is negated by the significant reduction in vacancy creation. Figures 6.14 - 6.17 below show the obtained impulse response functions of a skill biased technology shock with respect to different calibrations of the minimum wage rate.

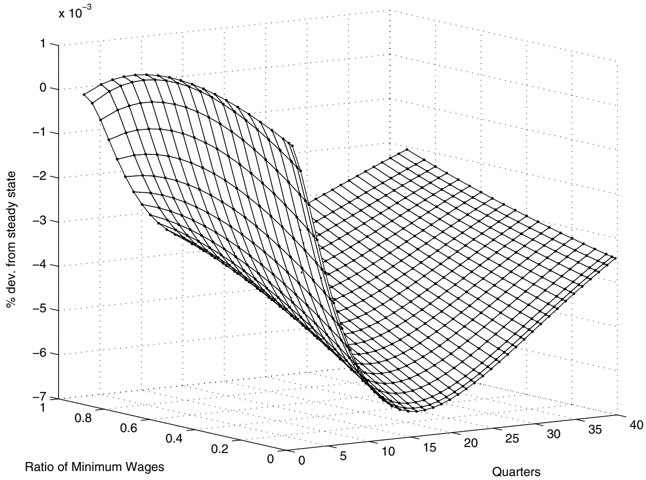

Fig. 6.14. Sensitivity analysis, employment h_u

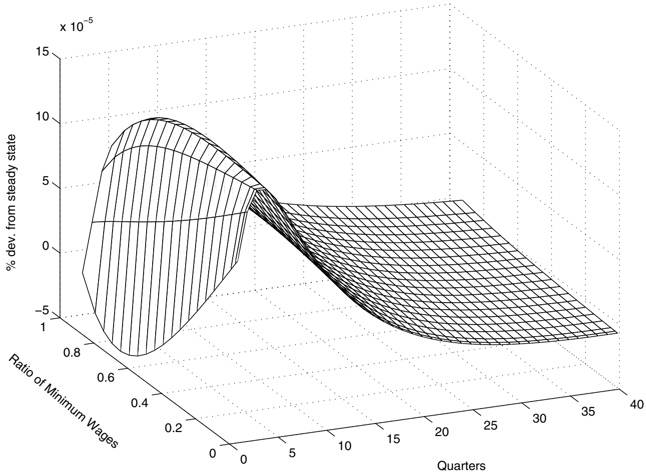

Fig. 6.15. Sensitivity analysis, search intensity s_u

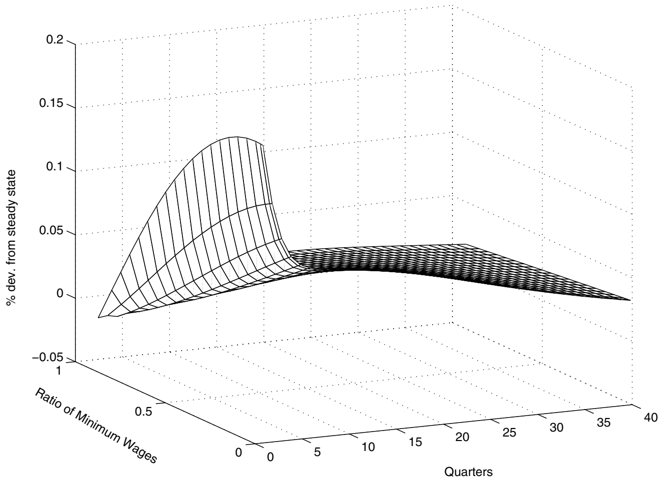

Fig. 6.16. Sensitivity analysis, vacancy creation v_u

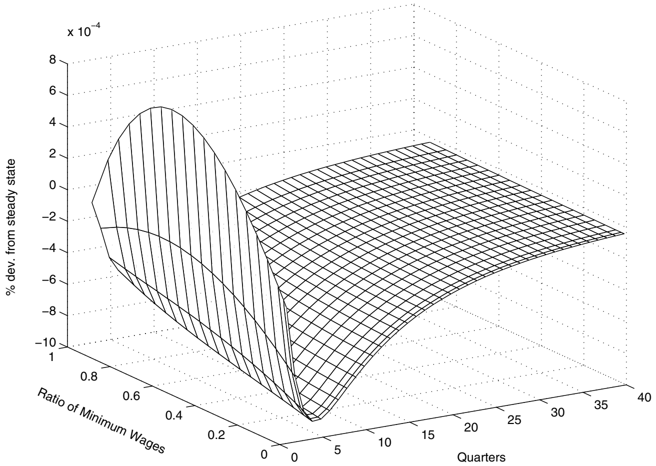

Fig. 6.17. Sensitivity analysis, job matches M_u

6.6 Long Run Policy Effects

The preceding analysis concentrated on the time perspective of the transmission process of technological advances under certain labor market policies. However, the question if labor market policies affect the long-run employment or the welfare of the economy is still open. Therefore, the steady state levels of employment and welfare are computed for a broad range of parameters. Furthermore, by defining a welfare function of the economy's agents the welfare effects of labor market policies are examined.

At first, we analyze whether the steady state level of a certain variable is determined by technological or policy parameters. Therefore, we study the effects of varying an important parameter of the production technology, i.e. the elasticity of substitution between both types of workers, and the policy parameter. Figure 6.18 below shows that the steady state employment level of low skilled workers of the minimum wage model. It is obvious that the employment level of low skilled workers is rather invariant with respect to changes in the elasticity of substitution between both types of workers. However, as the ratio of the minimum wage rule increases the employment level of low-skilled workers decreases significantly.

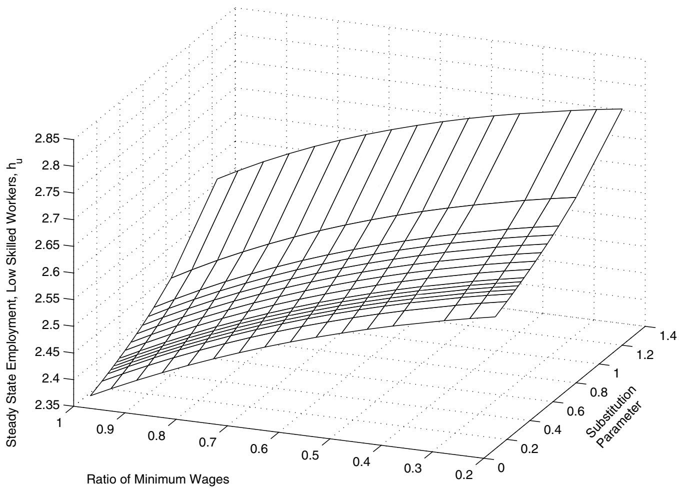

Fig. 6.18. Employment effects of wage policies for low-skilled workers.

On the other hand, the employment level of skilled workers is rather invariant over a broad range of parameter values. However, whether the minimum wage rule exceeds a certain threshold ($\varrho \approx 70$ %) a significant decline of the employment level of skilled workers is observed, too.

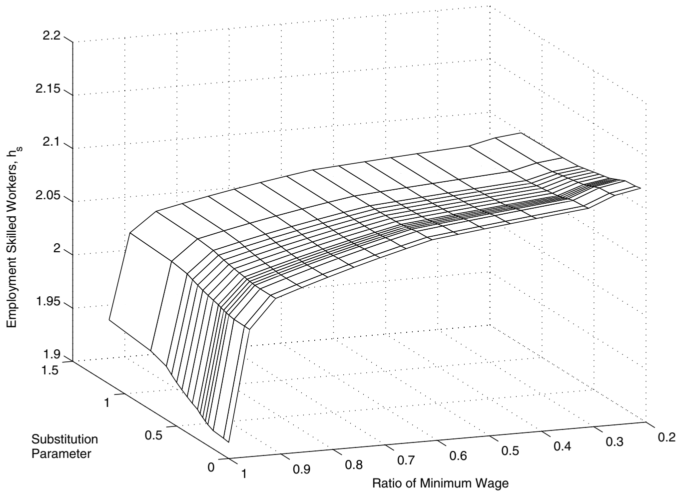

Fig. 6.19. Employment effects of wage policies for skilled workers.

By comparing the results to the model with employment protection mechanisms, it becomes obvious that firing taxes have no impact on the steady state employment level (see figure 6.20, below).

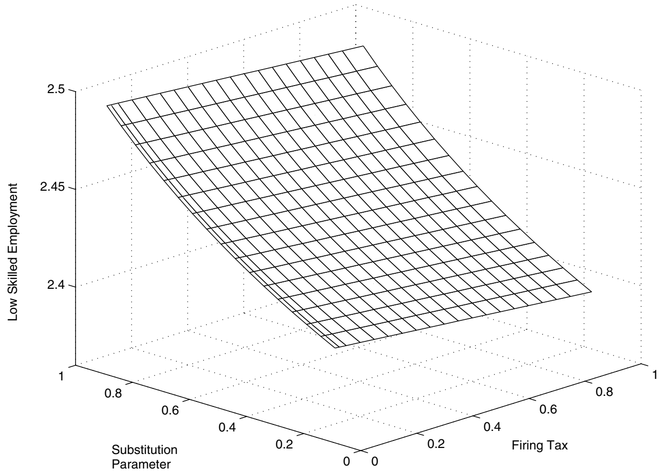

Fig. 6.20. Employment effects of firing taxes for low-skilled workers.

In particular the observation of the significant decline of the employment level of skilled workers in the minimum wage model (figure 6.19) leads to the conclusion that the income losses of the household might lead to a decline of the household's welfare. By defining the household's welfare at time t by the following function:

$$\Psi = U(c_t, h_{s,t}, h_{u,t}) + \beta U(c_{t+1}, h_{s,t+1}, h_{u,t+1}), \qquad (6.34)$$

where $U(\cdot)$ refers to the household's preferences as defined by equation (4.20). As shown by figure 6.21 the higher the rate of minimum wages the higher is the welfare loss of this economy. In particular, a significant decline is observed if the ratio of minimum wages exceeds 80% of the skilled worker's wage. Furthermore, as shown by figure 6.21, the higher the degree both types of workers become substitutes the higher is the long-run welfare gain of the economy. This can be seen by the increasing welfare level when the substitution parameter, σ_1, increases.

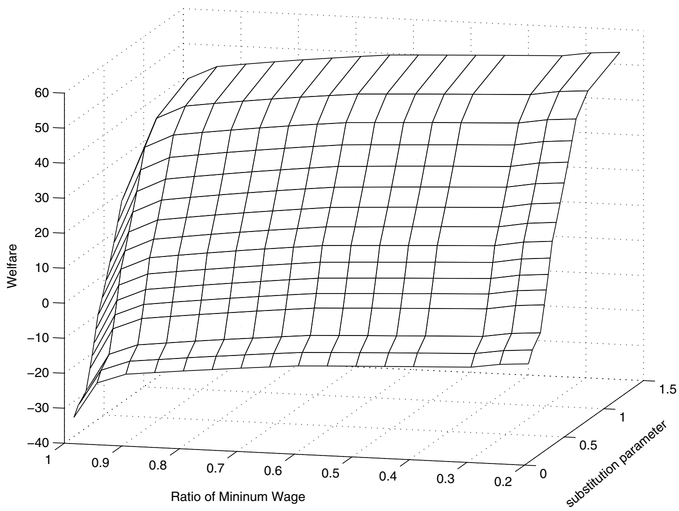

Fig. 6.21. Welfare effects of minimum wage rules

Beside the impacts of biased technology shocks on the employment pattern of the respective type of workers, the examination of the steady states shows that the long-run equilibrium of this economy is not invariant to policy measures. The comparison of the long-run effects of minimum wages and firing taxes shows that the steady state is rather invariant to changes in the amount of firing taxes. (figure 6.22). The analysis of the long-run effects of labor market policies shows that relative wage rigidities, in particular if they are too high, do not affect the short run dynamics alone. As shown by the welfare comparison of the different labor market policies (see figure 6.22 and 6.23) too high wage rigidities induce significant welfare losses.

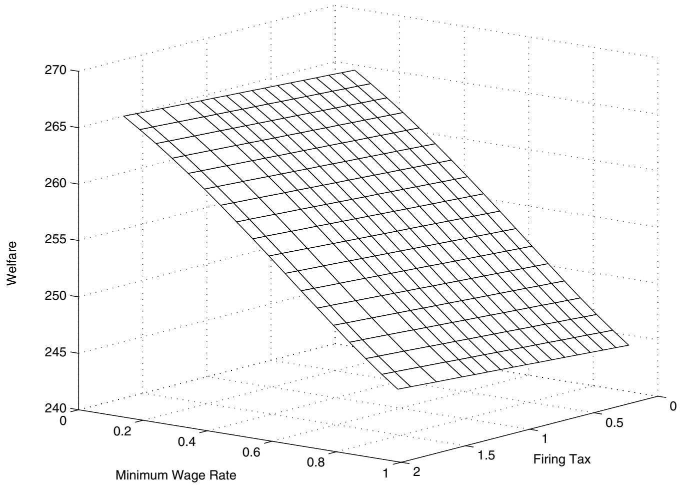

Fig. 6.22. Welfare effects of minimum wage rules and firing taxes

Another measure of welfare losses is given by the change of steady state output due to variations of the policy parameters (figure 6.23).

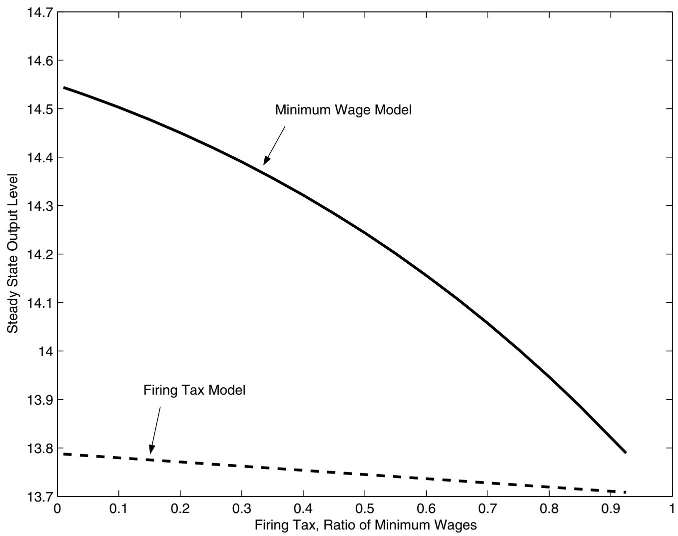

Fig. 6.23. Comparison of steady state output

Neglecting the level differences in steady state output, a significant and sharp reduction of steady state income is observed if the rate of minimum wages increases. This effect is particularly driven by the decline in employment of both skilled and unskilled workers.

6.7 Discussion

The analysis in this chapter has shown that labor market frictions and wage rigidities are important determinants for explaining the observed pattern of high unemployment of low-skilled workers during the last two decades. In particular, it has been shown, especially if we return to figures 6.1, 6.2, and 6.8, how the introduction of rigid wages for low-skilled workers affected the employment record for these types of workers.

Furthermore, the introduction of employment protection mechanisms due to firing costs does not lead to a persistent increase in unemployment. In addition, the results show that firing taxes increase the job duration for about 2 quarters. However, the results do not differ significantly from the baseline search model. The worst effects on the employment record of low-skilled workers is found if minimum wage rules are considered. A summary of the different effects of skill-biased technology shocks on the employment pattern of low skilled workers is shown in figure 6.24 below.

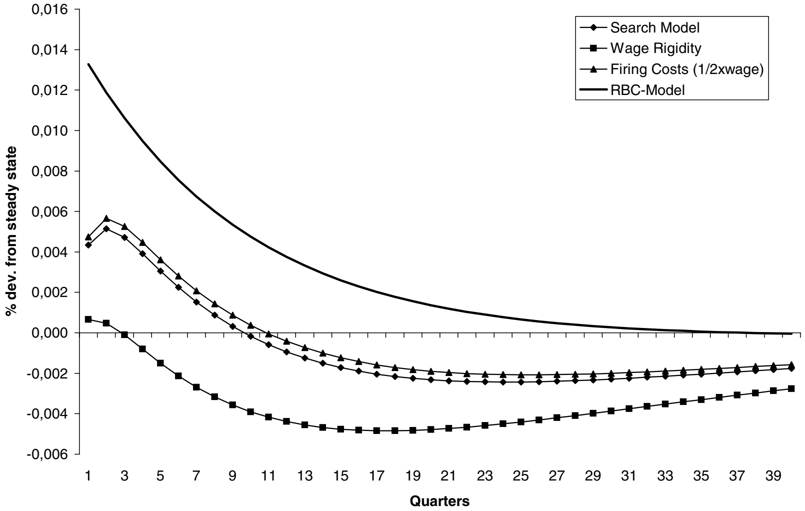

Fig. 6.24. Low-skilled employment: A comparison

If perfect labor markets are assumed, no negative response of the employment status of low skilled workers is obtained. The status of low-skilled workers worsens if labor market frictions are considered. In particular, no positive effect of an increase in productivity is found if wages for low-skilled workers are indexed to the skilled worker's wage. A comparison of the U.S. and Europe shows that the latter assumption unfortunately seems to hold. Furthermore, the results of chapter 6.5 could give a detailed explanation of the decline in employment of low skilled workers. This effect is particularly explained by the sharp decrease in job vacancies for low skilled workers (figure 6.16). Although job search activities of low skilled workers are high, a searching worker does not find a job.

Furthermore, we have shown that relative wage rigidities, in particular if they are too high, do not affect the short-run dynamics alone. As shown by the welfare comparison of the different labor market policies (see figures 6.21 to 6.23), excessive wage rigidity induces significant welfare losses.

7

Conclusion

Of course macroeconomics cannot be "exact;" it has to work by rough analogy and empirical compromise. Maybe a certain raffishness is inevitable.
(R.M. Solow (2000))

7.1 Summary

In 1994 Paul Krugman formulated the hypothesis that *... the European unemployment problem and the U.S. inequality problem are two sides of the same coin...*;[1] in general, he stated that skill-biased technological change leads to an increased demand for skilled workers and forces the wages of low-skilled workers to adjust downwards in order to secure low-skilled workers' employment. This explains the observation that the U.S. (un)employment pattern of different skill groups remained rather stable, whereas the unemployment rate of low-skilled workers exhibited a significant increase during the 1990s for continental European countries (see table 2.1). In particular, the general explanation of the rise of continental European unemployment is that labor markets are too rigid to ensure a downward adjustment of wages particularly for low-skilled workers.

Since the work of Krugman (1994), numerous studies have attempted to explain this pattern. However, most theoretical studies are based on an endogenous growth framework, as for example Ace-

[1] Cf. Krugman (1994) p. 37.

moglu (1998), Murphy, Riddel, and Romer (1998), or Aghion (2002), and many others. However, this branch of literature generally assumes perfect labor markets. On the other hand, the vast majority of examinations of wage inequality and relative employment are empirical examinations on a microeconometric level, such as, among others, Fitzenberger (1999), Card and DiNardo (2002), Puhani (2005). Although the empirical studies control for labor market variables, there is a lack of theoretical explanations of the interplay between technological change and the labor market.

At least since Ljungqvist and Sargent (1998), Acemoglu (1999) or Mortensen and Pissarides (1999), a further branch of literature has appeared which has provided a more sophisticated theoretical framework in which the interplay between technological progress and labor market outcomes can be studied. Whereas the article by Acemoglu (1999) extends an endogenous growth framework, the work by Mortensen and Pissarides (1999) primarily concentrates on a dynamic model of the labor market; influences of the business cycle, interrelationships between the agent's decisions and market outcomes were not taken into consideration.

The aim of this thesis was threefold. First to develop a dynamic general equilibrium framework that provides a theoretical explanation of the effects of technological advances on inequality and employment. Second, to develop a theoretical explanation for what kind of labor market institution causes the low or negative reaction of the employment of low-skilled workers. Third, to give empirical evidence on how the transmission process of technological advances affects wages and employment.

Based on a descriptive and an econometric examination, the main developments of U.S. and continental European labor markets were outlined. In general, the results confirm the findings of Saint-Paul (1996), that one observes two states of unemployment with different characteristics. In general, we observe rather low and stable unemployment rates of skilled workers and high and increasing unemployment rates of low-skilled workers (cf. table 2.1). Furthermore, significant differences in the bargaining structures, benefit payments and employment protection mechanisms described on the basis of current data. Based on the aggregate measures, a reduced-form VAR model was developed and estimated in order to examine the correlation of variables as well as to provide empirical evidence of the transmission process of the introduction of new technologies to wage inequality and employment. Although the main findings of the related literature were successfully reproduced on an aggregate level, the results cannot compete with microconometric evidence based on panel data, which are, generally used in order to examine relative wages and employment in more detail. As shown by most of the obtained impulse-response functions (see figures 2.8–2.10) technological change lead to positive reactions of the wage spread and to a positive reaction of relative employment. In particular, the negative response of the U.S. wage spread after an increase in the relative supply of skilled workers replicated the theoretical prediction of Acemoglu (1998). In addition we found similar effects of technology on the wage spread for Germany. However, an increase in relative employment has, in contrast to the U.S., a negative impact on the wage spread in Germany which might be interpreted as a strong supply effect. However, this result might be more related to the impact of German wage setting mechanisms which try to reduce inequality. From my point of view, the obtained results for Germany indicate strong insider effects on the labor market, leading to a declining wage spread and, on the other hand, to an increase in unemployment of low skilled workers because this group became too costly for the entrepreneurs. In addition, the effects of any unanticipated shock on the wage spread and relative employment lead to delayed or "hump-shaped" responses of these variables for both countries. This turned out to be an important result when trying to reproduce these responses theoretically.

The theoretical analysis of this thesis is subdivided into two parts: a first part in which the basic framework of a labor market with search and matching frictions is described and a second part in which this kind of labor market imperfection is introduced into a dynamic general equilibrium framework. The mere examination of the labor market has already revealed the necessity of numerical calibrations in order to study the employment pattern of different skill groups. There (cf. chapters 3.2 and 3.3), it was shown how wage inequality and the equilibrium outcomes of segmented labor markets react whether social benefits, technological progress or substitution elasticities change. In particular, the obtained results showed that it is generally possible to explain the cross-country differences in employment and wage inequality within one model framework in which the parameters are adjusted to country-specific characteristics.

However, the rather comparative static results of chapter 3 are not able to explain dynamic adjustment processes which arise due to technological advances and how these adjustment processes are influenced by market imperfections. In order to study the, to use the jargon of monetary economists, "transmission process" of technological change, two frameworks of dynamic general equilibrium models are developed in chapters 4 and 5. The first framework refers to the primary work of Kydland (1984, 1995) who introduced two kinds of labor into a dynamic general equilibrium framework. This framework was extended by the assumption of skill-biased technology shocks. By comparing the obtained results to time series evidence for the U.S. and Germany. There it was shown by the comparison of the obtained impulse-responses functions that this model framework was not able to account for the empirical facts. In particular, the results of the RBC-type model overstated the correlation of variables, in particular for wages and labor, and, furthermore, the obtained impulse-response functions do not show the hump-shaped response of the variables found in the data. Although a similar model such as developed, for instance, by Lindquist (2004) which considers the effects of capital-skill complementary on inequality and relative employment, is able to reproduce stylized facts of U.S. data, it is not able to account for labor market imperfections and empirical facts of European countries. In addition, as shown by the model of chapter 4, the assumption of imperfect capital-labor substitution does not improve the capability of the model.

In order to account for the effects of technological advances under the assumption of labor market imperfections, the assumption of search and matching frictions is introduced into the dynamic general equilibrium framework developed in chapter 4. Based on the pioneering work of Langot (1995), Merz (1995), and Andolfatto (1996), who study the implications of search and matching frictions in the context of a standard Real Business Cycle model, in chapter 5 their approach is extended by the introduction of two segmented labor markets as well as skill-biased technological change. In particular, the latter assumption refers to the work of Mortensen and Pissarides (1999). In comparison to the RBC-type framework, the latter model is able to reproduce empirically plausible impulse-response functions, which exhibit a hump-shaped pattern at reasonable magnitudes. Beside the improved capability of the model to reproduce some empirical evidence in contrast to the literature concerning the skill bias, we are now able to study these effects from a general equilibrium point of view and, furthermore, under the existence of unemployment and wage-setting institutions. By comparing the results to Lindquist (2004), it becomes obvious that the model with labor market frictions has deficiencies with regard to explaining the evolution of the U.S. wage spread; however, the model matches the pattern of relative employment for continental European economies.

Finally, the model developed in chapter 5 is intended to study the question concerning the determinants of the rise in unemployment of low skilled workers, in particular with regard to the influence of labor market institutions. In chapter 6 two important institutions are considered. First, it is assumed that the wages of low-skilled workers are indexed to the wages of skilled workers. In contrast to a pure wage rigidity which prevents an overall wage adjustment, for example due to wage agreements with a duration of several periods,[2] this assumption impedes the adjustment of relative wages. This is evident in

[2] This assumption is, in general, found in monetary models in order to ensure persistent real effects of monetary policy shocks. See, for example, Gerke (2003) or Gerke and Rubart (2006). In addition, the recent paper by Gertler and Trigari (2006) combines the assumption of Nash bargaining with staggered wage contracts.

countries like France or Germany where a rather constant educational wage spread is observed at the aggregate level (see, for example Katz and Autor (1999)). Basically, this model framework refers to the approaches of Pierrard and Sneessens (2003, 2004) and some suggestions of Hall (2005a), whereas the focus of the latter study is not on examining the unemployment pattern of low-skilled workers. Secondly, a firing tax is introduced into the search model. The latter assumption accounts for the fact that, in general, for central European countries, stronger employment protection mechanisms are in place, than for Anglo-Saxon countries. Finally, both approaches are combined within a single model. The comparison of the obtained results (see e.g. figure 6.24) has shown, that a rather low degree of relative wage rigidity causes the employment status of low-skilled workers to decrease continuously after an unanticipated shock in skill-biased technology. By contrast the assumption of firing costs has no significant effect in comparison to the search model discussed in chapter 5. Furthermore, the examination of the welfare effects of the two labor market policies has shown that a too high relative wage rigidity leads to significant welfare losses in the household's welfare.

All in all, the comparison to the RBC-type model that assumes perfect labor markets, approaches that incorporate a certain degree of labor market imperfection provide a better explanation of the effects of technological advances on the employment pattern of an economy.

Beside the transmission of technological advances to the labor market, we studied the incentives of firms and unemployed workers to create vacancies or to search for new jobs under specific labor market policies. There, we have shown that employment protection legislation, once it is known, has no significant impact on job search and vacancy creating activity. However, minimum wage rules have important influences on the economic agents and, unfortunately, lead to worse labor market outcomes, i.e. high unemployment, for low skilled workers. By comparing minimum wage rules with employment protection legislation, two important differences exist. First, wages or wage rules have higher impact on the agents' decision making, for instance, if the unemployed worker expects high wages he increases his job search activities persistently whereas the probability to stay employed for a longer period has no or little impact on the workers' decision. The second difference is that the wage rigidity or the minimum wage is not the result of a bargaining process, i.e. it is set outside the labor market and cannot be adjusted flexibly by firms and workers. For comparison, the firing taxes and benefit payments were parts of the bargaining process and also entered the job search and vacancy creation decision, however wages of both types of workers could adjust flexibly.

Furthermore, the results of chapter 6.6 have shown that labor market policies affect the economy in the long-run, too. In particular, we have shown that too high relative wages lead to significant losses in employment of both types of workers, welfare as well as steady state output. On the other hand, employment protection legislation has no or small effects on the long-run equilibrium.

7.2 Outlook

Although this thesis gave detailed insights into the transmission process of technological advances to the employment pattern of an economy, the capability of the analyzed models to reproduce business cycle facts has to be improved by future research. However, a comparison of the theoretical and empirical 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 that prevent the adjustment of relative wages explain the worse pattern of unemployment of low skilled workers. From this point of view, this thesis presented a theoretical discussion of the "Krugman - Hypothesis". In particular, it could be shown that the wage setting mechanism, mostly determined by the power of trade unions and the degree of bargaining coverage, accounts for this pattern. By contrast, employment protection mechanisms do not have significant effects on the employment status of low-skilled workers. In general, these findings reflect the observations, that European countries with strong employment protection mechanisms such as Sweden, Denmark do Finland, do not necessarily have high unemployment rates.[3]

As already mentioned, the aim of this thesis was not to regenerate the theory of Real Business Cycles via the introduction of heterogeneous labor nor to provide a better explanation of the business cycle. The main focus was to develop a framework which is able to account for the employment effects of technological change with regard to labor market institutions and to apply this framework to labor market policies of the recent political debate.

However, many questions remain open and lie, in parts, outside of the focus of this thesis and shall therefore be left for future research.

[3] Unemployment rates in 2004: Sweden: 6.5%, Denmark: 5.5%, Finland: 8.8%, France: 9.6%, Germany: 10.3%. See Eurostat, General and Regional Statistics, 3/2005. Note further that Nickell, Nunziata, Ochel, and Quintini (2001) report, for countries such as Sweden and Denmark, very high measures of employment protection.

First, because of the excessively high correlation of wages and employment, a revision of the search and matching approach should be taken into account. For example, den Haan, Ramey, and Watson (2000) provide a model with endogenous job creation and destruction, which exhibits a better reproduction of the stylized facts. Similar approaches have been published by Hall (2005b) and Shimer (2005). However, the latter models concentrate on the reproduction of the volatility of unemployment and vacancies rather on the employment pattern of different skill groups. Furthermore, the specification of the endogenous job destruction process seems difficult because one has to consider exogenous and endogenous productivity advances; however, if the effects of skill-biased technological advances are considered which might affect both types of workers, it seems difficult to clarify the "idiosyncratic productivity" shock which governs the job destruction rate of the type i worker.

Furthermore, in order to give a better explanation of the empirical evidences, a more sophisticated calibration of the models seems necessary. In particular, the parameter specification should be based on an estimated version of the model. However, up to now, there has been a lack of proper data. For example, an index of vacant jobs for low-skilled workers is not available, which is a variable that is important to estimate or to calibrate the respective matching functions.

Last but not least, further questions concerning displacement effects, where skilled workers apply for low-skilled jobs or active labor market policies such as on-the-job-training to increase job security, and human capital creation are not taken into account in this thesis. However, these questions seem more relevant if a medium-run or long-run perspective is taken into account. In particular, the latter questions concerning schooling effects, or human capital creation under the existence of labor market imperfections seem to be important for future research then, however, the model should be revised to an Overlapping Generations framework. However, the framework outlined in this thesis provides a logical starting point for studying these important questions.

A

Symmetric Technological Advances

The long-run effects on the wage spread of symmetric technological change are discussed in an endogenous growth model developed by Greiner, Rubart, and Semmler (2004). This appendix shows the simulation results of this approach within a dynamic general equilibrium framework with search and matching frictions. Basically, this setup refers to the model discussed in chapter 5. The main difference is the setup of the production technology as shown below. Analogous to Greiner, Rubart, and Semmler (2004), only one type of indexTechnology shock!Symmetric technology is assumed:

$$f(\cdot) = z_t \left(\alpha \big(\gamma (z_t^{\xi_s} h_{s,t})^{\rho_1} + (1-\gamma)(z_t^{\xi_u} h_{u,t})^{\rho_1} \big)^{\frac{\rho_2}{\rho_1}} + (1-\alpha) k_t^{\rho_2} \right)^{\frac{1}{\rho_2}}, \tag{A.1}$$

where z_t is determined by a stationary Markov process, i.e.

$$z_t = \rho z_{t-1} + \epsilon_t^z \qquad \text{with} \quad \epsilon_t^z \sim \mathcal{N}(0, \sigma^2).$$

Furthermore, the parameters $\xi_u, \xi_h > 0$ denote external effects of technology on the respective type of labor. The parameter settings for the calibration are chosen in accordance with table 4.1. Again, the main variables of interest are relative employment, the wage spread and the employment response of low-skilled workers. In order to evaluate this version of the model, the results are compared to the effects of a neutral technology shock of the model framework discussed in the previous chapters.

With the exception of the response of the wage spread (figure A.2), no qualitative differences to a neutral technology shock are observed. The higher magnitude and persistence of response of relative employment after a pure skill-augmenting shock can be explained by its greater direct impact on the productivity of skilled workers.

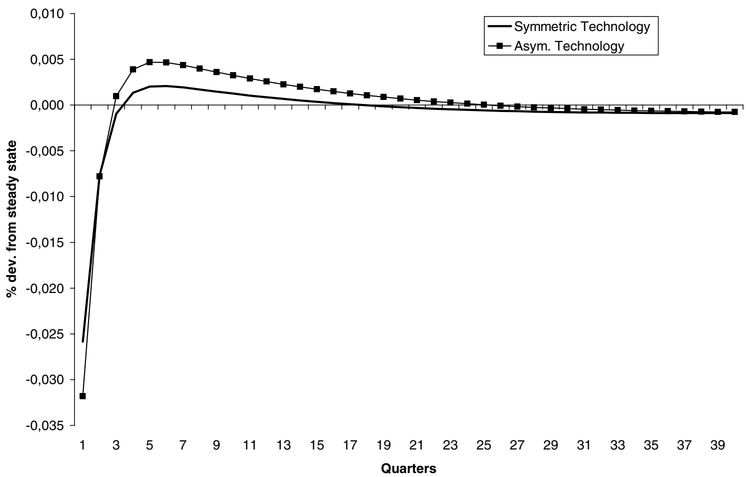

Fig. A.1. Relative employment

The higher response of the wage spread seems surprising, yet it can be explained by two effects. First, the general external effect, i.e. $\xi_s > \xi_u$ still holds. Furthermore, due to the lower increase in the employment of skilled workers, their marginal product increases, whereas due to the relatively high increase in low-skilled employment, the respective marginal product decreases, which has further dampening effects on the low-skilled wage.

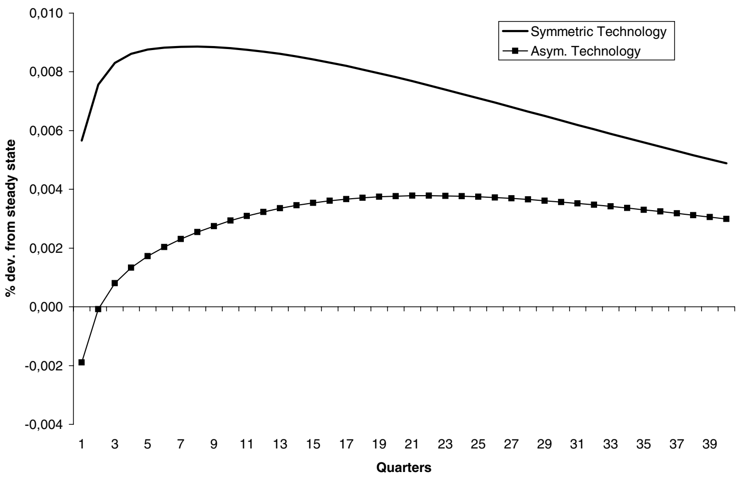

Fig. A.2. Wage inequality

The higher response of low skilled employment after a symmetric technology shock is explained due to this symmetry, i.e. the productivity of both types of workers increases, leading to higher employment. For comparison, an asymmetrical technology shock does not affect the productivity of another worker directly.

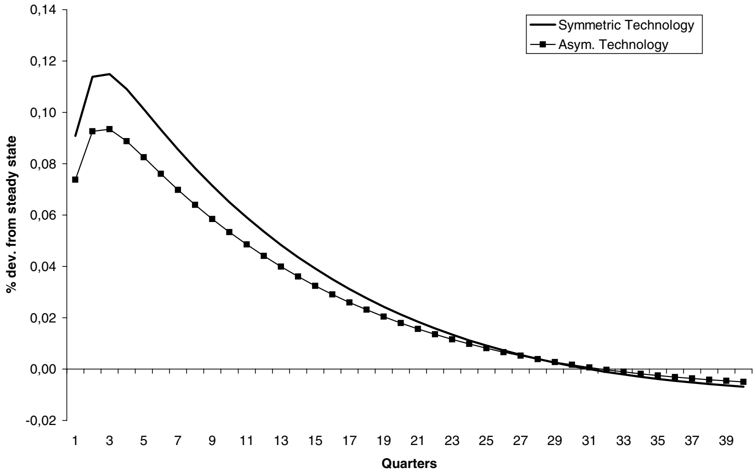

Fig. A.3. Employment of low skilled workers

B

Data, Sources and Definitions

- GDP, investment and capital stock:

  The time series of the GDP, and gross investment are taken from the OECD Economic Outlook 2005. The time series for the capital stock is taken from the OECD Business sector database (from 1964.1-1999.4). Please note, that all data are real data measured in prices of 2000.

- Labor productivity:

  Real output per employed person in the business sector (OECD definition). Business sector employment is defined as total economy employment less public sector employment. Business output is defined as real GDP less the government real wage bill less net real indirect taxes less real consumption of fixed capital. Thus, business output is valued at factor costs. The series are taken from OECD Economic Outlook 2005.

- Unemployment and vacancies:

  The U.S. unemployment data are taken from the Bureau of Labor Statistics (www.bls.gov) and are based on monthly observations. 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. The general time series of unemployment rates and job vacancies are taken from OECD Main Economic Indicators 2005. The vacancy rate is computed as the vacancy - employment ratio.

- Employment of high and low-skilled workers:

  Based on annual data for the U.S. and Germany which are linearly 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 the 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, Rubart, and Semmler (2004) for a similar data set.

- 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 (see OECD (2003)). The quarterly data applied in chapters 2.1 and 2.3.2 are obtained from linear interpolation.

- Wage spread:

  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 Current Population Survey (CPS) and show the ratio of wages for workers with some sort of college degree to workers with a high school degree. The quarterly data applied in chapters 2.1 and 2.3.2 are obtained from linear interpolation.

C

Solow Residual and Labor Productivity

In order to estimate the Solow residual from a standard growth accounting exercise, the following functional form is applied:

$$\frac{\dot{y}}{y} = \bar{\alpha} + \alpha \frac{\dot{k}}{k} + (1-\alpha)\frac{\dot{l}}{l} + \epsilon. \tag{C.1}$$

In particular, two measures of the stock of capital are applied in the estimations. The time series of the capital stock is a quarterly series provided by the OECD Business Sector Database from 1964.1 to 1999.4. The second measure, which is used to calculate the residual, is based on an own calculation of the capital stock by applying the perpetual inventory method, i.e. $k_{t+1} = (1-\delta)k_t + I_t$ where a constant depreciation rate of 2.5% per quarter is assumed. Please note that I_t denotes gross investments. Furthermore, according to Greiner, Rubart, and Semmler (2004), the initial value of this series is approximated as: $k_0 = I_0/(\delta + \bar{g}_I)$, with g_I as the mean growth rate of gross investments. When calculating the capital stock, a quarterly depreciation rate of $\delta = 0.025$ is assumed.

The parameter α is estimated by OLS, where the following values are obtained for the U.S. and Germany:

$$\alpha^{\text{U.S.}} : 0.29(0.022) \qquad \alpha^{\text{Germany}} : 0.23(0.028),$$

where the terms in parentheses denote the respective standard errors. Both parameters turned out to be highly significant and within reasonable ranges.[1]

The relationship between labor productivity and the Solow residual is studied by an OLS estimation to the following equation

$$g_x^{\text{LP}} = \beta_0 + \beta_1 g_x^{\text{Solow}} + \varepsilon. \tag{C.2}$$

Note that g_x^{LP} denotes the growth rate of labor productivity and g_x^{Solow} the Solow residual, respectively. For both countries, β_1 turned out to be highly significant. For the U.S. the following results are reported:

$$\beta_1 = 0.908(0.034) \qquad R^2 = 0.835$$

for Germany

$$\beta_1 = 0.874(0.080) \qquad R^2 = 0.476,$$

with standard errors in parentheses.

[1] Please note that the break in the German time series due to reunification in 1990 is omitted in the OLS regression.

The high correlation of both series is also documented by figure C.1 below:

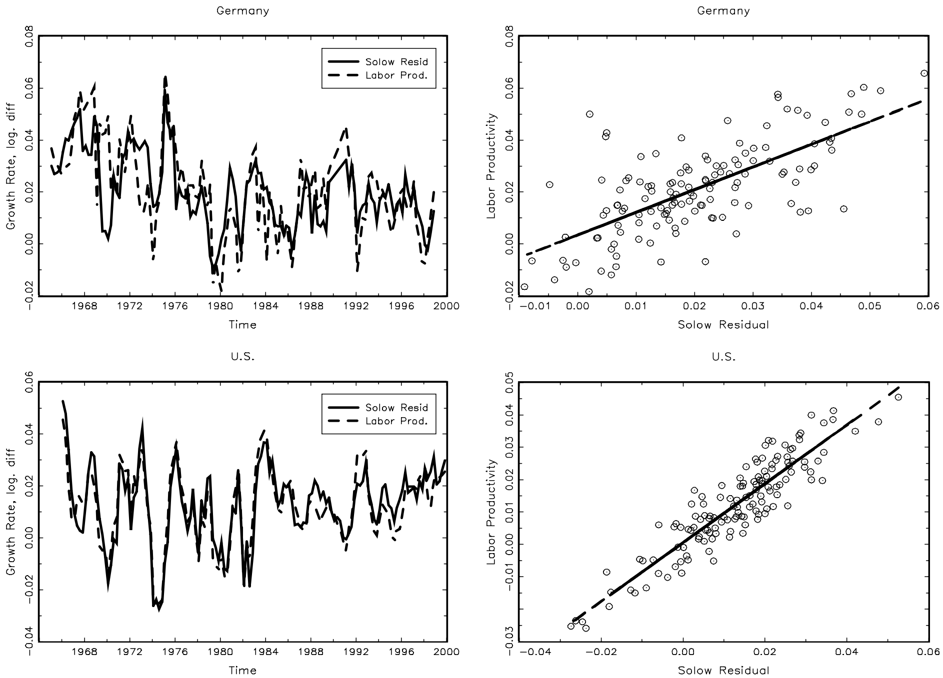

Fig. C.1. Labor productivity and the Solow residual

D

A Brief Description of DYNARE

DYANRE is a pre-processor and a collection of MATLAB or SCILAB routines which solve non–linear models with forward looking variables. It is available at: `http://www.cepremap.cnrs.fr/dynare/`. Note, that in this thesis the Matlab version of DYNARE, rel. 3.064, is applied.

DYNARE computes[1]

- the steady state of a model
- the first and second order approximations to the solution of stochastic models
- computes theoretical and / or simulated moments as well as impulse response functions
- estimates parameters of DSGE models by using the maximum likelihood or Bayesian approach (not used in this thesis).

DYNARE solves the following, general form, of an economic model:

$$E_t\left[f(y_{t+1}, y_t, y_{t-1}, u_t; \theta)\right] = 0,$$

with

[1] Parts of this summary of DYNARE are based on lecture notes by Stephane Adjemian of his course held at the Deutsche Bundesbank in April 2006.

y : vector of endogenous variables

u : vector of exogenous shocks with $E[u_t] = 0$ and $E[u_t u_t'] = \Sigma_u$

θ : vector of parameters

In general, the unknowns in a stochastic framework are the decision rules that have to be approximated. The approximated decision rules and transition equations are of the following form

$$y_t = \bar{y} + A\hat{y}_{t-1} + Bu_t,$$

with $\hat{y}_t = y_t - \bar{y}$. Where $\bar{y}$ denotes the steady state value of the respective variable. Furthermore, A and B denote matrices of parameters.

The system of equations is, determined by the Euler equations of the household's and the firm's optimization problem, the resource constraints, the law of capital accumulation and the exogenous shocks. In the case of search and matching models, the evolution of employment and the matching function have to be considered, further.

The DYNARE code for the RBC-type model (cf. chapter 4) is given as an example, below

```
periods 1000;

var y, i, c, k, r, w_s, w_u, h_s, h_u, z, w_i; varexo e;

parameters beta, rho, alpha, gamma, exs, exu, phi, delta, sigma, s,
u, n_u1, n_u2;

alpha = 0.64;
s     = 1/3;
u     = 2/3;
rho   = 0.95;
beta  = 0.99;
delta = 0.025;
phi   = 0.5*1;  %default = 0.5
```

```
sigma = 1.4;     % int.: 1.01 - 2.0
gamma = .5;
n_u1   = -.8;
n_u2   = -.8;  % default=-.8
exs    = 1.5;
exu    = 1;

model;
 y        = c + i;
 k        = (1-delta)*k(-1) + i;
 y        = exp(z)*k(-1)^(1-alpha)*(gamma*(exp(z)^exs*h_s)
            ^((sigma-1)/sigma)+(1-gamma)*(exp(z)^exu*h_u)
            ^((sigma-1)/sigma))
            ^(alpha*sigma/sigma-1);
 r        = (1-alpha)*y/k(-1);
 c^(-phi) =beta*(c(+1)^(-phi)*(1+r(+1)-delta));
 w_s      = k(-1)^(1-alpha)*exp(z)^(1+exs*(sigma-1)/sigma)*gamma
            *(gamma*(exp(z)^exs*h_s)^((sigma-1)/sigma)
            +(1-gamma)*(exp(z)^exu*h_u)^((sigma-1)/sigma))
            ^(alpha*sigma/(sigma-1)-1)*h_s^(-1/sigma);
 w_u      = k(-1)^(1-alpha)*exp(z)^(1+exu*(sigma-1)/sigma)
            *(1-gamma)*(gamma*(exp(z)^exs*h_s)
            ^((sigma-1)/sigma)
            +(1-gamma)*(exp(z)^exu*h_u)^((sigma-1)/sigma))
            ^(alpha*sigma/(sigma-1)-1)*h_u^(-1/sigma);
 -(1-h_s)^(-n_u1) = c^(-phi)*w_s;
 -(1-h_u)^(-n_u2) = c^(-phi)*w_u;
 w_i = gamma/(1-gamma)*exp(z)^((exs-exu)*(sigma-1)/sigma)
       *(h_s/h_u)^(-1/sigma);
 z = rho*z(-1)+ e;
end;

initval; y = 7.60; c = 4; k = 12; h_s = .3; h_u = (1-h_s); w_s =
3.8; w_u = 2; w_i = 1.9; i= 1.5; r = 0.05; z = 0; e = 0; end;

steady(solve_algo=2);

shocks;
var e=0.07^2;
end;

stoch_simul(dr_algo=1,order=1,irf=40,replic=20,
            hp_filter=1600,simul,simul_seed=1)
```

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