Labor Market Reforms:
An Evaluation of the Hartz Policies in Germany

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Abstract
We evaluate worker and firm behavior in response to the German Hartz reforms using detailed micro data. The comprehensive Hartz labor market changes were implemented between 2003 and 2005 to reduce unemployment, by increasing working hour flexibility, job matching and work incentives. Our evaluation of these comprehensive reforms accounts for heterogeneous effects on workers and firms. We exploit the dynamics of the model for identification and estimate by maximum likelihood using matched data on around 430,000 workers employed in 340,000 firms from 2001-2005. Contrary to previous findings, our evaluation shows that the reforms marginally reduced unemployment at the cost of a pronounced reduction in wages. Furthermore, we decompose the contribution of each reform wave on employment and wages, and document a structural shift in the factors that govern overall wage dispersion after the reforms. Match specific and frictional wage variation become relatively more prominent after the reforms, while the importance of firm and sorting effects is reduced.

Keywords: labor market policy, Hartz reforms, job search, wages, employment
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1 Introduction

Evaluating the impacts of labor market policies on employment rates and wages is not straightforward. Often labor market reforms that aim to increase employment have important effects on wages by changing incentives, search behavior and sorting of workers and firms. This paper proposes a new method for analyzing policies with pronounced differential impacts by worker and firm type. We apply this approach to evaluate the effects of a comprehensive recent labor market reform package in Germany, the Hartz reforms. The objective of these reforms was to reduce unemployment, by implementing four reform laws in 2003, 2004 and 2005. We develop a structural framework that is empirically tractable to evaluate the aggregate effects of these reforms. We assess the relative importance of individual reforms and decompose the effects into changes in the composition of worker, firm and match specific heterogeneity, search frictions and sorting by using worker-firm matched data. Our framework is identified from the dynamics of the model and is estimated using a maximum likelihood procedure. As a result, we do not rely on convergence of the economy to its steady-state for identification and statistical inference is simplified. These features make our approach suitable for evaluating complex labor market policy changes in settings where detailed worker-firm data are available.

The German labor market reforms in the early 2000s are often referred to as exemplary policies for reducing unemployment. After lackluster economic growth in the 1990s and early 2000s, Germany outperformed many other industrialized countries from 2006 on and during the Great Recession. Unemployment fell from 12.3% in 1998 to 8.7% in 2008, and Germany attracted international attention for its transformation from the ‘sick man of Europe to economic superstar’ [Dustmann et al. 2014]. Other less prominent explanations for the strengthening of the German economy include pre-reform wage moderation and a favorable export environment. In particular the decrease in unemployment is often attributed to the Hartz reforms. It remains unclear to what extent the Hartz reforms altered the performance of the German labor market, and how they affected employment and wages.

To evaluate these effects of the Hartz reforms, we estimate worker and firm behavior in response
to the policies by using detailed German administrative data on 430,000 workers and 340,000 firms. Our estimation shows that overall the three Hartz reform waves resulted in a small expansion of employment of 0.8 percentage points. This expansion is smaller than the employment impact often attributed to the reforms. Furthermore, this employment increase comes at the cost of an 8.4% reduction in mean wages. We also find large differences in the contributions of each reform wave to the overall effect. The first wave, which promoted labor demand, would lead to a reduction in employment and wages if implemented in isolation. By contrast the second wave, which aimed at improving the matching process, by itself would be expansionary in both employment and wages. Overall, we find that the reforms lead to a structural shift in the sources of wage variation. As a consequence of the first reform wave, the importance of the match specific wage component increases relative to the firm specific component. In addition, wage variation due to sorting falls after the reform as a consequence of diminished worker outside options, which is primarily driven by the reform wave that decreased unemployment benefit generosity. Longer employment spells result in a greater amount of frictional wage dispersion, which arises in our context when a worker uses new job offers to bid up wages.

In assessing labor market reform impacts, existing studies often concentrate on either modeling specific reform elements or providing a terse analysis of the policy impact in aggregate. In evaluating the Hartz reforms, one strand of the literature uses macroeconomic time series of the in- and outflows of employment and tests for breaks in the series at the time of reform implementation. Fahr and Sunde (2009), Klinger and Rothe (2012) and Hertweck and Sigrist (2013) model the job finding rate through matching functions and treat the Hartz reforms collectively as a shock to matching efficiency. Fahr and Sunde (2009) only account for the first two reform waves and find a modest expansion of employment. Hertweck and Sigrist (2013) document a large employment effect of the Hartz reforms, and results in Klinger and Rothe (2012) indicate a positive impact of the reforms on matching efficiency and consequently employment. A second set of papers focuses on the contents of individual Hartz reforms and models them explicitly. In calibrated models, Krause and Uhlig (2012) and Krebs and Scheffel (2013) point to a substantial positive employment impact associated
with the decrease in unemployment benefit generosity, a main element of the final Hartz reform wave. On the other hand, the structural models estimated in Launov and Wälde (2013, 2016) imply that the unemployment benefit change has a negligible effect on the reduction of unemployment. Their models feature asset accumulation and consumption contingent on benefit duration. Launov and Wälde (2016) also include reform elements of the second wave modeled as a shift in matching efficiency, which in their setting is four times more effective than the final reform wave at reducing unemployment. This literature offers even less consensus with respect to the wage impact of the Hartz reforms. Krause and Uhlig (2012) and Krebs and Scheffel (2013) find that the final wave depressed wages, with a 12.5% wage cut for the low-skilled. By contrast, in Launov and Wälde (2013) wages increase in response to lower unemployment benefits because of lower endogenous taxation and increased market tightness.

The conceptual approach of our paper is a hybrid of these two classes of models. Our setting differs from a more reduced form approach as in Fahr and Sunde (2009), Klinger and Rothe (2012), and Hertweck and Sigrist (2013), which lacks the necessary structure to examine individual policies within a reform. Furthermore, employment and wages exhibit a high degree of persistence, so the impact of a policy is likely to take a long time to be fully realized. Fully-fledged structural models on the other hand such as those by Krause and Uhlig (2012), Krebs and Scheffel (2013), and Launov and Wälde (2013, 2016) already contain significant complexity to capture just one or two reform elements. These type of models cannot easily be expanded to investigate the specifics of wide reaching labor market reforms. One of the only approaches to reform evaluation that is similar to ours is developed by Murtin and Robin (2016), who assume that the parameters of the structural model are governed by specific labor market policies. While we exploit changes in policy within a country over time, Murtin and Robin (2016) identify the mapping between policy and parameters from cross-country differences, and restrict attention to employment and its volatility.

We develop and estimate a structural framework of the labor market that is simplified by not modeling reform policy changes explicitly. Instead we assume that policy can be described as a set of structural parameters that characterize the labor market. These parameters change with the
implementation of new policy. In our model reforms can affect wages and employment through a number of channels, such as search frictions and heterogeneity in worker, firm and match specific productivity. Wages are the result of a bargaining game between the worker and firm, and the wage setting mechanism varies according to the employment status of the worker. Our model extends the framework in Lise and Robin (2016), by including a match specific component, a wage setting mechanism that can match the empirical wage distribution, and shocks that affect the parameter space rather than labor productivity. Since the reforms were widely discussed in public before their implementation in Germany, we assume that all changes are fully anticipated and that the structural parameters evolve according to a deterministic process. This novel approach is significantly more tractable. We can estimate the parameters by maximum likelihood and obtain identification through the dynamics of the model. By contrast, conventionally, this type of model is estimated in a static environment by means of a method of moments estimator. Identifying the parameters from off steady-state dynamics is preferable because wages and employment are persistent, and we do not need to rely on the labor market being in steady-state after the last policy implementation. Furthermore, maximizing a likelihood function rather than a set of moment conditions makes inference more straightforward.

This paper is organized as follows. Section 2 provides an overview of the Hartz reforms, summarizes the evolution of employment and wages over the reform periods and motivates our conceptual approach. Section 3 describes the model. The estimation protocol is presented in Section 4. Section 5 presents the estimation results and simulates the model to uncover the overall and individual reform impacts on wages and employment. Section 6 concludes.

2 The Hartz Reforms

The Hartz reforms consist of four labor market reform laws that were implemented in Germany between 2003 and 2005. The main objective of the reforms was to reduce unemployment. To reach this objective the reforms included extensive changes for workers and firms, such as increased working hour flexibility, improved job matching and more stringent work incentives for the unemployed.
The Hartz laws were based on suggestions by the Commission for Modern Services in the Labor Market, also called the Hartz Commission. After years of rising unemployment, labor market policy was a central issue in the German elections in 1998 and 2002. When unemployment remained high the Hartz Commission was appointed on February 22nd 2002 in response to a scandal, which revealed that the Federal Employment Agency had significantly embellished the numbers of successfully placed job seekers. The Hartz Commission was composed of 15 experts from industry, politics and academia, and named after the chairman of the Commission, Peter Hartz, who was CEO of Volkswagen at the time. The Commission published its suggestions for labor market policy changes in August 2002. These suggestions led to the Hartz reform package, which was implemented from January 1st 2003 onward. Figure 1 gives an overview of the timing and content of the Hartz I-IV laws, and Supplementary Appendix B.1 provides more details on the reform contents. Broadly summarized, the first wave aimed at raising labor demand, the objective of the second wave was to improve market efficiency, and the target of the final wave was to increase labor supply.

Figure 1: The timing and content of the Hartz reforms 2002-2005

The Hartz I and II reforms came into effect on January 1st 2003. Hartz I, the first of the four ‘Laws for Modern Services in the Labor Market’, facilitated temporary employment and introduced

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1The Supplementary Appendix can be found on the personal websites of the authors.
new training subsidies. Hartz II further regulated marginal employment, introduced mini- and midi-jobs, and sponsored business startups by the unemployed. Mini-jobs provide tax exemption for worker contributions to social security for monthly incomes up to 400 Euros, and midi-jobs allow tax deductions for incomes up to 800 Euros a month. The third reform law, Hartz III, was implemented from January 1st 2004 on, and restructured the Federal Employment Agency with the objective of making it a modern client-oriented service provider. Hartz IV came into effect on January 1st 2005, and was one of the most extensive and controversial labor market reforms that was ever implemented in Germany. It significantly changed the generosity of unemployment benefits and the reduced the duration of benefit receipts, partly combined unemployment benefits with social assistance payments, introduced asset-based means testing for benefit receipt, and included sanctions to promote more active job search. The effects of Hartz IV for individual benefit receipts were ambiguous. For example, households with low incomes in employment and single parents profited from the reform while those with higher employment incomes experienced a reduction of benefits (Koch and Walwei 2005).

2.1 The Reform Effects

To examine the impact of the Hartz reform laws we use data on 430,000 males working in 340,000 firms from the Sample of Integrated Labor Market Biographies (SIAB) between 2001 to 2005. The data are stratified into three skill groups. Workers with an intermediate school leaving certificate or below are defined as unskilled, workers with a vocational qualification such as an apprenticeship and with an upper secondary school certificate are combined in a medium skill group, and university graduates are classified as high skill workers.

2.1.1 Employment

Figure 2 plots unemployment rates and unemployment durations for new hires by skill group between 2000 and 2006. The dates of the announcement and implementations of the Hartz reforms are denoted by vertical dashed and solid lines respectively. All monthly series have been seasonally
adjusted using the X-12-Arima program.\footnote{X-12-Arima is a software package developed by the US Census Bureau for seasonally adjusting time series data. Further details are available at 
\url{https://www.census.gov/srd/www/x12a/}}

Figure 2: Unemployment rates and duration 2000-2006

![Graph showing unemployment rates and duration from 2000 to 2006.](image)

(a) Unemployment rates  
(b) Unemployment duration

**Note:** Unemployment rates are constructed from Benefit Recipient History data that is a part of the SIAB dataset. Unemployment duration refers to months of unemployment for workers who exit unemployment. The monthly series are based on SIAB data and are seasonally adjusted using the X-12-Arima program.

As shown in panel (a) of Figure 2, unemployment increases during the implementation of the reforms between 2003 and 2005 and falls after the Hartz IV law comes into force in 2005. The increase in unemployment is already visible from the initial announcement of reforms after the appointment of the Hartz Commission in February 2002. With the implementation of the fourth Hartz law, unemployment rose to a historical high with over 5.2 million workers unemployed. This unemployment spike in January 2005 is largely due to a change in unemployment benefit legislation in Hartz IV, which required spouses of the long-term unemployed to register as unemployed to be eligible for benefits. The duration of unemployment exhibits more volatility than the unemployment rates. Duration is reported for new hires who exit unemployment and is defined as the time for which a worker was unemployed since his last employment spell, as recorded in the Benefit Recipient History data source. By contrast to the unemployment rate, the duration series displays a u-shaped
pattern in Figure 2. In times of high (low) unemployment, new hires have on average spent less (more) time in unemployment. Changes in the worker composition of the pool of unemployed are one potential explanation for this pattern. Our model accommodates such composition changes by accounting for worker heterogeneity.

Figure 3: Transition rates 2000-2006

(a) Job finding rates

(b) Separation rates

**Note:** Job finding rates are the monthly shares of unemployed workers who find a job. Separation rates capture the monthly share of employed workers who exit into unemployment. The monthly series are based on SIAB data and are seasonally adjusted using the X-12-Arima program.

Panel (a) in Figure 3 shows the outflows from unemployment and panel (b) the inflows into unemployment. The series indicate that the increased unemployment over the implementation period is primarily driven by a fall in the job finding rate, and the post-reform fall in unemployment is associated with a higher job finding rate. Separation rates increase slightly for the unskilled over the reform periods. Unskilled workers have the highest separation rates and these remain higher post-2005 compared to the pre-reform period.
2.1.2 Wages

The monthly mean and standard deviation of log real daily wages for workers hired from unemployment are reported in Figure 4. Log real daily wages for new hires show a pronounced decline for all skill groups and a corresponding increase in the standard deviation of wages. Wages are measured in Euros, which are deflated using the Consumer Price Index published by the German Federal Statistical Office.

Figure 4: Log real re-entry wages 2000-2006

(a) Log real re-entry wages
(b) Standard deviation of log real re-entry wages

Note: Log real re-entry wages refer to the natural log of daily wages in Euros for new hires, which are deflated by the Consumer Price Index. The monthly series are based on SIAB data and are seasonally adjusted using the X-12-Arima program.

Before announcing the appointment of the Hartz Commission on February 22nd 2002, both series appear relatively stable. A large change in wages coincides with the introduction of the Hartz reforms. Over the reform periods mean log wages fall across all three skill strata, with the unskilled and lowest paid bearing the bulk of the decrease. Raw wages for low-skilled new hires fall by over 50% over this period, and the dispersion of wages increases within each skill strata. In our framework wages are set endogenously, so that our model can uncover the drivers of this structural change.
2.2 Conceptual Approach

This paper develops a framework for assessing the marked decrease in wages that occurred contemporaneously with the Hartz reforms. Due to the comprehensive impact of the Hartz reforms, standard reduced form or structural approaches are not suitable for analyzing the effects on wages and employment. The approach we implement uses both elements of a reduced form analysis and a structural model. In our model the structural parameters follow a stochastic process that responds to labor market interventions. Instead of modeling each reform element explicitly we treat a reform wave as a shock to the parameter space.

A reduced form evaluation compares outcomes before and after a specific policy is implemented, which is not feasible in the context of the Hartz reforms. It is likely that firms and workers anticipated the Hartz policy changes before the implementation of the reform policies and adjusted their behavior before the first Hartz reform and until Hartz IV took effect. A reduced form assessment may also fall short because of the persistence of the endogenous variables, employment and wages. To evaluate the impact of any such reform fully would require data for an extensive time period after the last policy was implemented. An alternative approach would impose full structure on the data generating process and specify each policy explicitly in a structural model. The Hartz reforms, however, were so wide-ranging that modeling all different reform features is unrealistic.

In our structural setting we include important sources of wage dispersion to shed light on the effects of the Hartz reforms. Building on the literature on wage dispersion, our model can account for variability in wages due to observable and unobservable worker differences, firm productivity, a match specific component, search frictions, and sorting across all these dimensions.

3 The Model

3.1 The Environment

Time is continuous and denoted by $t$, where $t \in \mathbb{R}_+$. Parameters subscripted by $t$ vary over time, and $\theta_t$ denotes the vector of parameters at time $t$. The structural parameters of the model evolve
according to a jump process that occurs at the instance of the introduction of each labor market reform wave. Changes to $\theta_t$ are fully anticipated by the agents, but in order to keep the problem static, the exact instance at which the policy is implemented is not known. Instead, risk neutral agents know the instantaneous probability that a policy will be implemented. The Poisson rate $\eta_t$ is calibrated to match the frequency of the Hartz reforms. Assuming that agents do not know the exact implementation dates makes the setting tractable. Instead of an infinite number of states, at any point in time the Poisson process ensures only five possible states between the announcement and implementations of individual policy, as shown in Figure [I]

The labor market consists of a continuum of infinitely lived workers of mass one, who are indexed by their level of productivity $x \in (\underline{x}, \overline{x})$. Workers can either be employed or unemployed, and the measure of workers of productivity $x$ is given by $\ell(x)$. When a worker is unemployed he receives a flow utility value $b_t(x)$. A continuum of firms exist that are indexed by their productivity $y \in (\underline{y}, \overline{y})$. When a worker is hired by a firm, the amount produced depends on the productivities of the worker and the firm as well as on a match specific draw, $z \in (\underline{z}, \overline{z})$. The match specific component $z$ is drawn from a known distribution with density $\gamma(z)$, which is independent of worker and firm productivities. The decision whether to form a match is made after the realization of $z$. A worker and firm of productivity $x$ and $y$ with a match specific productivity draw $z$ produce an amount $f_t(x, y, z)$, where $f_t : (\underline{x}, \overline{x}) \times (\underline{y}, \overline{y}) \times (\underline{z}, \overline{z}) \to \mathbb{R}_+$. Our initial assumption for the functional form of $f_t(x, y, z)$ is that as $z \to \overline{z}$, $f_t(x, y, z) \to \infty$.

The economy is characterized by search frictions and workers cannot observe the full menu of jobs. Instead job offers arrive randomly to a worker at time $t$ with an exogenous Poisson arrival rate $\lambda_{0,t}$ if the worker is unemployed and $\lambda_{1,t}$ if the worker is employed. The sampling density of firms is fixed over time and given by $\nu(y)$. Jobs are destroyed at an exogenous rate $\delta_t$, after which the worker becomes unemployed.
3.2 Wage Determination

Wages are fully flexible and can be re-negotiated either after an alternative job offer arrives or when the state of the world changes through policy shocks. Supplementary Appendix B.2 shows that our estimation results are unlikely to rely on the assumption of flexible wages by describing the consequences of a model with less flexible wages. In our baseline setting, an employment contract can be thought of as a fixed threat point in a Nash bargaining game, and employment can be terminated at will or destroyed exogenously. In either case the worker becomes unemployed.

For an unemployed worker, wages are determined as in Cahuc et al. (2006) and Dey and Flinn (2005), where a firm hires a worker from unemployment and the worker and the firm split the surplus. The worker receives a fraction $\beta$ of the generated surplus and the firm receives the rest. When a worker is employed, however, wages are determined as in Postel-Vinay and Robin (2002), where on the job search triggers Bertrand competition between a worker’s current employer and the poaching firm. If the unemployed worker’s bargaining power $\beta$ were equal to zero, then wages are determined as in Postel-Vinay and Robin (2002). This combination of well known wage setting mechanisms allows us to retain much of the tractability of the setting in Postel-Vinay and Robin (2002) while allowing more flexibility over wage formation.

For a given wage $w$, the surplus is shared between the worker and the firm. $W_t(\cdot)$ denotes the value function of an employed worker, $U_t(\cdot)$ is the value function of an unemployed worker, $\Pi_t(\cdot)$ is the value function of a firm that hires a worker, and $S_t(x, y, z)$ is the total surplus generated by a match.

$$W_t(w, x, y, z) - U_t(x) + \Pi_t(w, x, y, z) = S_t(x, y, z)$$

It is assumed that the outside option of the firm is zero. The wage provides an unemployed individual with an additional value equal to $\beta S_t(x, y, z)$. The wage of a worker’s first job after

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As in Cahuc et al. (2006) and Dey and Flinn (2005), the relationship between entry wages and firm type is ambiguous. Workers are willing to accept lower wages today knowing that they will be compensated with higher wages tomorrow, which is the only mechanism at play in Postel-Vinay and Robin (2002). Since workers take a fraction $\beta$ of the surplus, however, the wage is higher when the surplus is larger. The magnitude of $\beta$ mostly determines which effect dominates.
leaving unemployment is a function of his productivity, the firm’s productivity and the match 
specific draw, and denoted by $\phi_0(x, y, z)$. If a positive surplus is generated then it is in the interest 
of the worker and the firm to form a match. Thus the values of $y$ and $z$ that result in matches for 
the worker are a function of his own productivity $x$ and given by $M_0(t) = \{y, z | S_t(x, y, z) \geq 0\}$. The wage solves the following equality:

$$W_t(\phi_0(x, y, z), x, y, z) - U_t(x) = \beta S_t(x, y, z). \tag{2}$$

### 3.3 Wage Mobility

When a firm meets an employed worker, the poaching firm draws a match specific productivity 
that is observable to all parties. The incumbent and the poaching firm then engage in Bertrand 
competition to hire or retain the worker. For a worker of productivity $x$ employed in a firm of 
productivity $y$ with match specific productivity $z$, three possible things can happen.

**Move jobs**: The worker moves if the surplus generated from the poaching firm is greater than 
the current surplus generated. The set of poaching firm and match specific productivities $y'$, 
$z'$ is given by $M_{10}(x, y, z) = \{y', z' | S_t(x, y', z') \geq S_t(x, y, z) \geq \beta S_t(x, y', z')\}$. Due to asymmetries in the wage 
bargaining process between employed and unemployed workers, however, the determination 
of the new wage remains ambiguous. We therefore partition $M_{1,t}(x, y, z)$ into $M_{10,t}(x, y, z)$ 
and $M_{11,t}(x, y, z)$, where, $M_{1,t}(x, y, z) = \{M_{10,t}(x, y, z) \cup M_{11,t}(x, y, z)\}$.

The more familiar case is when new offers $(y', z')$ are in the set $M_{11,t}(x, y, z)$ and the set is 
defined as $M_{11,t}(x, y, z) = \{y', z' | S_t(x, y', z') \geq \beta S_t(x, y', z')\}$. In this instance 
the worker moves to the new firm and uses his current employment as his outside option in 
Bertrand competition. The new wage of the worker is given by equation (3) and he is able to 
extract all the surplus from his former match.

$$W_t(\phi_{1,t}(x, y', z', y, z), x, y', z') - U_t(x) = S_t(x, y, z) \tag{3}$$

If the surplus generated between the poaching firm and the incumbent firm, however, is 
sufficiently large, when $(y', z') \in M_{10,t}(x, y, z)$ and $M_{10,t}(x, y, z) = \{y', z' | \beta S_t(x, y', z') >$
\(S_t(x, y, z)\}, then the worker gets a larger share of the surplus if he uses unemployment as his outside option. After meeting a higher surplus match, the worker instantaneously quits his current job and bargain with the poaching firm as an unemployed agent. The worker’s new wage is defined in equation (2).

**Stay in the same job with a wage increase**: The worker receives a within firm promotion if the surplus generated by a new offer is high enough to trigger Bertrand competition with the incumbent firm but not higher than the surplus of the current match. Bertrand competition is triggered if the surplus of a new match is greater than the worker surplus in the current match. Formally, the set of \(y', z'\) is defined as \(M_{2,t}(w, x, y, z) \equiv \{y', z'|S_t(x, y, z) > S_t(x, y', z') > W_t(w, x, y, x) - U_t(x)\}\). The worker’s new wage solves the equality:

\[
W_t(\phi_{1,t}(x, y, z, y', z'), x, y, z) - U_t(x) = S_t(x, y', z').
\]

**No change**: If a worker receives an offer that generates less surplus than he is already taking from his current match, then the incumbent firm does not need to offer a higher wage to retain the worker. The set of \(y', z'\) is defined as \((y', z') \setminus M_{1,t}(x, y, z) \cup M_{2,t}(w, x, y, z)\).

### 3.4 Wage Re-Negotiation

There are two types of shocks. Either a shock takes the form of an announcement of future changes to the parameter set, in which case agents re-optimize, or it is a direct shock to the parameter set. Wages are flexible and wages are re-negotiated after shocks take place. Wages are re-negotiated assuming the worker has the same firm-match outside option \((y', z')\). The worker can only use this outside option as a bargaining tool with his current employer, and we do not consider the possibility of changing employers. This re-negotiation mechanism ensures tractability.

We describe an alternative approach with greater wage rigidity in Supplementary Appendix B.2, which leads to identical wage distributions in steady-state with slightly different wage dynamics. Unlike mechanism presented here, however, wage equations are computationally more expensive as they require solving a fixed point.
After a shock, a match either dissolves and the worker returns to unemployment, or wages are re-negotiated.

**The match separates**: The match dissolves if the participation (positive surplus) constraint no longer holds. The set of time varying parameters $\theta_{t'}$ immediately after a shock, for which a $(y, z)$ match with a worker of productivity $x$ is endogenously destroyed, is given by $N_{0, t'}(x, y, z) = \{\theta_{t'} | S_{t'}(x, y, z) < 0\}$.

If a worker’s outside option is unemployment, the outcome of the wage re-negotiation is trivial.

Before the shock a worker of type $x$ in a match $(y, z)$ earned a wage $\phi_{0, t}(x, y, z)$. After a shock, as long as the match is not separated, $\theta_{t'} \notin N_{0, t'}(x, y, z)$, the worker’s new wage is given by $\phi_{0, t'}(x, y, z)$. These wages are determined as the solution to the equality given by equation \[2\].

If the same worker in the same match with an outside offer $(y', z')$ and currently earning $w := \phi_{1, t}(x, y, z, y', z')$, however, is hit by a shock, his new wage is re-negotiated in one of three ways. In each case we denote the new wage as $w'$, which can be a function of a worker’s type $(x)$, his job type $(y, z)$ and his best outside option $(y', z')$.

**Use the same outside offer**: The worker’s new wage is re-negotiated using the same firm match threat point if $\theta_{t'}$ is such that

$$N_{1, t'}(x, y, z, y', z') \equiv \{\theta_{t'} | S_{t'}(x, y, z) \geq S_{t'}(x, y', z') \geq \beta_{t'} S_{t'}(x, y, z) \geq 0\}.$$  

In this scenario the match remains incentive compatible. The worker uses the same threat point when bargaining with his incumbent firm, and the new wage is given by

$$w' = \phi_{1, t'}(x, y, z, y', z').$$

**Use unemployment as outside offer:**

$$N_{2, t'}(x, y, z, y', z') \equiv \{\theta_{t'} | \beta S_{t'}(x, y, z) > S_{t'}(x, y', z') \geq 0\}$$

Given the above, a worker gains a greater share of the surplus using unemployment as a threat point as opposed to his previous best outside option. In the re-negotiation procedure
he bargains with unemployment as his outside option and his new wage is given by

\[ w' = \phi_{0,t}(x, y, z) \]

The worker takes all the surplus:

\[ N_{3,t'}(x, y, z, y', z') \equiv \{ \theta_{t'} | S_{t'}(x, y', z') > S_t(x, y, z) \geq 0 \} \]

Finally, it could be that after realization of the new parameter set the outside option of the worker generates a larger surplus than continued employment with his current firm. In our setting, workers cannot move to previous job offers, as in such a case a change in policy would increase job mobility by construction. In this case we assume the worker has all the bargaining power and is able to extract the entire surplus. His new wage is given by

\[ w' = \phi_{1,t'}(x, y, z, y, z) \]

### 3.5 The Surplus

This class of models has the advantage that only the expression that defines the surplus needs to be solve. By contrast, solving for the worker and firm individual value functions would involve five (rather than three) continuous variables. The surplus function is given by equation \[ (4) \] and is formally derived in Appendix A.1. The + superscript denotes \( A^+ := \max\{A, 0\} \).

\[ (r + \delta_t + \eta_t)S_t(x, y, z) = f_t(x, y, z) - b_t(x) - \beta \lambda_{0,t} \int \int S_t(x, y', z')^+ v(y') \gamma(z') dy' dz' + \lambda_{1,t} \int \int [\beta S_t(x, y', z') - S_t(x, y, z)]^+ v(y') \gamma(z') dy' dz' + \eta_t S_{t'}(x, y, z)^+ \] (4)

Equation \[ (4) \] describes the surplus generated by a match and is the fundamental equation of the model. It dictates the decisions of agents about who to match with and determines the resulting wages from consummating the match. The surplus consists of the net gain in flow utility, output minus home production, and three option values. The first integral term is the option premium in unemployment, the value of future employment to the unemployed. We refer to the second integral...
term as the quit premium. The quit premium is the additional surplus generated by being able to use unemployment as a worker’s outside option. Since this expression is non-negative, it increases the total number of feasible matches. The final term represents the agent’s expectations about the time varying parameters after a shock. If future parameters, $\theta_{t'}$ generate more (less) surplus than the current parameters this adds (reduces) value to the current surplus and further encourages (deters) realizing a match today.

We solve equation (4) numerically. Since the surplus at $t$ depends on the surplus at $t'$, it is solved by backward induction. Furthermore, one does not need to form expectations about the value of the future surplus because the policy implications are anticipated. This makes the solution far simpler in computational terms and also means we do not need to make distributional assumptions about agents’ beliefs. An additional computational burden arises due to the quit premium. Unlike the option value of unemployment, the set $M_{10,t}(x, y, z)$ over which we integrate is a function of $y$ and $z$. Under the majority of parameterizations that we have experimented with, however, this constitutes a relatively small share of total surplus and it thus proves computationally more efficient not to update this term at every iteration.

**Lemma 1** As $z \to \xi$, $S_t(x, y, z) \to \infty$.

Lemma 1 is proved in Appendix A.2.1.

**Proposition 1** The set,

$$M_{xy}^t \equiv \left\{ x, y \left| \int_\xi^\infty 1\{S_t(x, y, z) \geq 0\} \gamma(z) dz > 0 \right\}$$

is equal to the universe of $(x, y)$, that is $M_{xy}^t : (\xi, \tilde{x}) \times (y, \tilde{y})$.

Proposition 1 is proved in Appendix A.2.2. The set of all feasible worker-firm matches at time $t$ is given by $M_{xy}^t$. The fact that this set covers the universe of $(x, y)$ suggests that all worker-firm pairs are feasible. No worker-firm match observed empirically can be used to falsify the model.

**Lemma 2** For any $x, y, y'$ and $z'$, there is a $z$ such that $S_t(x, y, z) > S_t(x, y', z')$.

---

4Solving by backward induction relies upon the final state being absorbing. After Hartz IV it is assumed that agents anticipate no further reforms, and $\eta_t = 0$ at a time $t$ that is sufficiently large, as described in Section 3.7.
Lemma 2 is proved in Appendix A.2.3.

Proposition 2 The set

\[ \mathcal{M}_{1,t}^{y} (x, y, z) \equiv \{ y', z' | S_t(x, y', z') \geq S_t(x, y, z) \cap y > y' \} \]

is non-empty for all \((x, y, z)\).

Proposition 2 follows directly from Lemma 2. In equilibrium any employed agent may voluntarily move to a less productive firm. We use the type of job mobility defined in Proposition 2 as an identification argument for the variation in the match specific component \(z\).

3.6 Wage Equations

The wage a worker receives depends on whether he has any outside options in employment. The outside option affects the current wage either because the worker moved from one employer to another or because he received sufficiently good job offers while with his current employer. Equation (5) represents the wage of a worker of type \(x\) in a firm of type \(y\) and a match specific draw of \(z\) with no outside options. This case arises for all workers who join a firm from unemployment.

\[
\phi_{0,t}(x, y, z) = f_t(x, y, z) \left[ (1 - \beta) (r + \delta_t + \eta_t) S_t(x, y, z) \right. \\
- (1 - \beta) \lambda_{1,t} S_t(x, y, z) \int \int_{y', z' \in \mathcal{M}_{1,t}(x,y,z)} v(y') \gamma(z') dy' dz' \\
- \lambda_{1,t} \int \int_{y', z' \in \mathcal{M}_{2,t}(x,y,z)} \left[ S_t(x, y', z') - \beta S_t(x, y, z) \right] v(y') \gamma(z') dy' dz' \\
+ \eta_t (1 - \beta) 1 \{ \theta_t' \notin N_0, t' (x, y, z) \} S_{t'}(x, y', z')
\]

Equation (5) is derived by solving the equality given by equation (2). This derivation and the formal definitions of the integral supports are provided in Appendix A.3. A worker of type \(x\) in a firm of type \(y'\) with match specific draw \(z'\) who has previously received an offer from a firm of type \(y\) with match specific draw \(z\) receives a wage given by equation (6). This wage is derived by solving the equality given by equation (3). The derivation and the definition of all sets are given.
in Appendix A.4

\[
\phi_{1,t}(x, y, z, y', z') = f_t(x, y', z') \\
- \lambda_{1,t} \int \int_{y'', z'' \in M_{11,t}(x, y, z)} [S_t(x, y, z) - S_t(x, y', z')] \nu(y'') \gamma(z'') dy'' dz'' \\
- \lambda_{1,t} \int \int_{y'', z'' \in M_{2,t}(x, y, z)} [S_t(x, y', z'') - S_t(x, y, z')] \nu(y'') \gamma(z'') dy'' dz'' \\
+ \eta_1 \{ \theta_{t'} \in N_{2,t'} (x, y, z, y', z') \} \left[ S_{t'} (x, y', z') - \beta S_{t'} (x, y, z) \right] \\
+ \eta_1 \{ \theta_{t'} \in N_{3,t'} (x, y, z, y', z') \} \left[ S_{t'} (x, y', z') - S_{t'} (x, y, z) \right]
\]

(6)

Proposition 3 The set

\[
\mathcal{M}_{1,t}^{w-} (w, x, y, z) \equiv \{ y', z' | S_t(x, y', z') \geq S_t(x, y, z) \cap \phi_{1,t}(x, y', z', y, z) < w \}
\]

is non-empty for some \((t, w, x, y, z)\).

Bertrand competition between employers for employed workers retains the attractive feature of Postel-Vinay and Robin (2002) that some employment transitions are associated with a wage cut. The worker accepts a wage cut because he is sufficiently compensated by the increase in the option value of future job offers. The proof for this mechanism proof is provided in Appendix A.5. Since Proposition 2 is for all \((x, y, z)\) the set \(\mathcal{M}_{1,t}^{w-} (w, x, y, z)\) defined above can be partitioned further, by conditioning on an increase or decrease in firm productivity. In this way, the model is able to generate any combination of increase or decrease in wage or firm productivity.

3.7 Labor Dynamics

Rather than modeling the specifics of each reform package, we implement the Hartz policy waves as a series of shocks to the structural parameters of the model. The impact of each reform package on the parameter space is fully anticipated. At time \(t\) agents believe policies arrive at a Poisson arrival rate \(\eta_t\). This model feature is somewhat unrealistic because agents are likely to know the exact date of the reform in the immediate lead up to a policy implementation. Since in our setup agents are risk neutral, however, uncertainty over the exact timing of the policy is not important. Furthermore, before the formation of the Hartz Commission on February 22\textsuperscript{nd} 2002 and after the implementation of Hartz IV on January 1\textsuperscript{st} 2005, agents believe the parameter space is stable

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indefinitely. In these two stable periods, the probability that the parameter space changes is zero, \( \eta_t = 0 \). Therefore, from equation (4) the value of the surplus in a match \((x, y, z)\) at time \(t\) is equal to the value of the surplus in the same match for any \(t' > t\).

The two stable periods can be solved for independently of the evolution of the structural parameter set before or after the reforms. There are three periods when agents anticipate further change to the parameter set, which we refer to as the unstable periods. These unstable periods take place after the announcement but before implementation of Hartz I and II, after Hartz I and II but before Hartz III, and after Hartz III but before Hartz IV. In the unstable periods, the surplus generated of a match today depends on how the structural parameters will evolve in the future. These structural parameters therefore are solved for sequentially by backward induction.

In the first stable period before the reforms were anticipated the distribution of unobservables \((x, y, z)\) among matched agents or the distribution of worker type \((x)\) among the unemployed are unclear. The initial allocation of worker, firm and match types is consequential for the effects of the reforms. For simplicity we assume that the economy that the economy is in steady-state before the reform is announced, which seems reasonable because the last recession in Germany occurred almost a decade earlier in 1993.

### 3.7.1 Initial Steady-State

We assume that the economy is in steady-state before the reforms are announced in February 2002. For ease of exposition we consider a steady-state in this subsection, which implies that the measures of unemployed and employed workers of every productivity combination are stable. For unemployed workers, the flow out of unemployment of workers of any productivity \(x\) is equal to the inflow, which is expressed in equation (7). The measure of unemployed agents of productivity \(x\) is denoted by \(u(x)\) and \(e(x, y, z)\) is the measure of employed agents of productivity \(x\), in a firm of productivity \(y\) with match specific productivity \(z\).

\[
u(x) \left[ \lambda_0 \int \int_{y',z'\in M_0(x)} v(y') \gamma(z') dy' dz' \right] = \delta \int \int e(x, y', z') dy' dz' \quad (7)
\]

The total measure of workers of productivity \(x\) in the economy at large is \(\ell(x)\), so that the right
hand side of equation (7) simplifies to $\delta [\ell(x) - u(x)]$. Rearranging, the measure of unemployed agents of productivity $x$ is

$$u(x) = \frac{\delta \ell(x)}{\delta + \lambda_0 \int_{y',z' \in M_0(x)} \nu(y') \gamma(z') dy' dz'}.$$  

Similarly, the flow out of the measure $e(x, y, z)$ is equalized with the inflow, captured in equation (8). We express this equation in terms of surplus conditions rather than feasible matching sets, as it is written in other papers.

$$u(x) \lambda_0 \{S(x, y, z) \geq 0\} \nu(y) \gamma(z) \int \int \{S(x, y, z) \geq S(x, y', z')\} e(x, y', z') dy' dz' = \delta e(x, y, z) + \lambda_1 e(x, y, z) \int \int \{S(x, y', z') \geq S(x, y, z)\} \nu(y') \gamma(z') dy' dz'$$

Unlike the expression for the measure of unemployed agents, we implement an iterative solution algorithm for solving this integral equation.

### 3.7.2 Labor Adjustment

A series of shocks to the parameter space are realized, corresponding to the initial announcement of the reforms and the subsequent reform implementations. At the incidence of the $i^{th}$ shock, at $t = t_i$, an instantaneous adjustment in labor assignment takes place. All matches that generate negative surplus after the new realization of the parameter space are separated. Time $t_i^-$ denotes the time immediately before $t_i$. Formally, $t_i^-$ is given by $t_i^- = \lim_{\epsilon \to 0^+} (t_i + \epsilon)$. Equation (10) shows the immediate readjustment of the measure of unemployment.

$$u_{t_i^-}(x) = u_{t_i^-}(x) + \int \int_{y, z \in M_0(x)} e_{t_i^-}(x, y, z) dy dz$$

The first term represents the unemployed from the previous period and the second term are the employed agents who no longer generate a positive surplus after the new realization of the parameter space in $t_i$. The pre-shock measure of employed individuals in period $t_i$ of productivity $x$ in firm $y$ with match specific component $z$ is conditional on positive surplus still being generated, and expressed in equation (11).

$$e_{t_i}(x, y, z) = \{S_{t_i}(x, y, z) \geq 0\} e_{t_i^-}(x, y, z)$$
After the shock is realized, the labor market continues to adjust in the stable period. Equation (12) is a differential equation in \( t \) that defines the evolution of the measure of unemployed agents. The first term is the inflow into unemployment from the exogenous separation of employed agents and the second term is the outflow, the flow rate at which the unemployed find work.

\[
\dot{u}_t(x) = \delta_t (\ell_t(x) - u_t(x)) - \lambda_{0,t} u_t(x) \int \int_{y,z \in M_{0,t}(x)} v(y') \gamma(z') dydz \tag{12}
\]

This equation can be solved for \( u_t(x) \) and the solution is given below. Intermediate steps are presented in Appendix A.6. The contemporaneous steady-state unemployment measure \( u_{ss,t}(x) \) is obtained by the analogous solution to equation (8) at time \( t \) and \( u_t(x) \) is the measure of agents in unemployment at the time of the last shock, the solution to equation (10).

\[
u_t(x) = u_{ss,t}(x) \left( 1 - \exp \left[ (\delta_t + \lambda_{0,t} \int \int_{y,z \in M_{0,t}(x)} v(y') \gamma(z') dydz) (t_i - t) \right] \right) + u_{t_i}(x) \exp \left[ (\delta_t + \lambda_{0,t} \int \int_{y,z \in M_{0,t}(x)} v(y') \gamma(z') dydz) (t_i - t) \right] \tag{13}
\]

The dynamics in the same stable period of the measure of ability \( x \) workers in \((y,z)\) match at time \( t \) is given by equation (14), which consists of the inflow from unemployment, the inflow from lower surplus employment, the outflow to unemployment, and the outflow to higher surplus employment respectively.

\[
\dot{e}_t(x, y, z) = u_t(x) \lambda_{0,t} \{S_t(x, y, z) \geq 0\} v(y) \gamma(z) + \lambda_{1,t} v(y) \gamma(z) \int \{S_t(x, y, z) \geq S_t(x, y', z')\} e_t(x, y', z') dy' dz' - \delta_t e_t(x, y, z) - \lambda_{1,t} e_t(x, y, z) \int \{S_t(x, y', z') \geq S_t(x, y, z)\} v(y') \gamma(z') dy' dz' \tag{14}
\]

This equation is more complex due to the term describing inflow from lower surplus employment, which introduces non-linearities that do not exist in the differential equation for unemployment. We solve equation (14) numerically, as to our knowledge it cannot be solved analytically.

### 4 Data and Estimation

This section describes how we construct macroeconomic time series for the German labor market, and parameterize and estimate the model. We provide details about the data generating process,
the likelihood function, and fit of the parameter estimates in matching the time series. The model is simulated so it matches the data series from January 2001, over 13 months before the formation of the Hartz Committee, until the end of 2006, 12 months after the implementation of the last Hartz reform. For estimating we split the data into a pre-reform period from January 2001 to January 2002, an announcement period from February to December 2002, the implementation of Hartz I and II from January to December 2003, the implementation of Hartz III from January to December 2004, the implementation of Hartz IV from January to December 2005, and a post-reform period from January to December 2006.

Instead of just the permanent worker type $x$, we now further distinguish skill by observable worker skill characteristics. Assuming a segmented labor market we stratify the sample and estimate the model by skill group, indexed by $k$. Our data includes information on eight skill levels that we use to allocate workers into three skill groups. Workers with an intermediate school leaving certificate or below are defined as low-skilled, workers with a vocational qualification such as an apprenticeship and with an upper secondary school certificate (Abitur) are combined into a medium-skill group, and university graduates are classified as high-skill. For observations with missing skill information, we impute the skill group by following the IP1 procedure in [Fitzenberger et al.] (2006), which for a given worker extrapolates skill information and ensures skill is monotonically increasing over time.

The model presented in the previous Section is fully parameterized and we estimated the structural parameters. Our assumptions about the data generating process make an analytically tractable likelihood function feasible. Similar models typically rely on method of moments or indirect inference for estimation. Our approach to maximize a likelihood function is novel, and makes inference significantly more straightforward.

4.1 The Data

To examine the impact of the Hartz reforms we use the Sample of Integrated Labor Market Biographies (SIAB), a German worker-firm dataset. The SIAB is a 2-percent random sample drawn from
administrative data and links information on workers from German administrative data with firm information from the Establishment History Panel. We restrict the estimation sample to male full-and part-time workers between the age of 20 and 60, who are not in vocational training. This choice of age group means most individuals in the sample have finished their education and are working. Individual daily employment spell data are available from administrative data for employees covered by social security. Around 80% of the German labor force are covered by compulsory social security contributions, which exclude the self-employed, public sector workers and military employees. The SIAB also includes unemployed workers but does not provide information on out of the labor force status. Data access to the SIAB is provided via on-site use at the Research Data Centre of the German Federal Employment Agency at the Institute for Employment Research (IAB) and subsequently by means of remote data access.

The mean of daily real wages for employed workers in our sample is 74.12 Euros and 45.74 Euros for newly hired workers re-entering employment. Unemployed workers receive an average daily benefit payment of 24.47 Euros. 10% of observations are low-skill workers with an average wage of 48.73 Euros, 76% are medium-skill with an average wage of 66.61 Euros and 14% are high-skill workers earning an average wage of 105.11 Euros. The sizes of the three skill groups are relatively constant, with some decline in the number of low- and medium-skill workers and a small increase of high-skill workers. The number of workers and the proportion of top-coded wages by skill group are reported in Table 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>Share top-coded</th>
<th>Share re-entry top-coded</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S1</td>
<td>S2</td>
</tr>
<tr>
<td>2001</td>
<td>36,715</td>
<td>267,482</td>
<td>46,209</td>
<td>0.005</td>
<td>0.054</td>
</tr>
<tr>
<td>2002</td>
<td>35,825</td>
<td>264,221</td>
<td>46,740</td>
<td>0.005</td>
<td>0.053</td>
</tr>
<tr>
<td>2003</td>
<td>35,303</td>
<td>264,665</td>
<td>46,991</td>
<td>0.002</td>
<td>0.033</td>
</tr>
<tr>
<td>2004</td>
<td>35,014</td>
<td>262,941</td>
<td>47,200</td>
<td>0.002</td>
<td>0.034</td>
</tr>
<tr>
<td>2005</td>
<td>36,491</td>
<td>263,518</td>
<td>47,623</td>
<td>0.002</td>
<td>0.033</td>
</tr>
</tbody>
</table>

Note: S1, S2 and S3 refer to low-skill, medium-skill and high-skill workers, respectively.

Wages reported in German social security data are subject to top-coding so that wages above
threshold are censored at the threshold value, which is defined for each year and separately for West and East Germany. We apply these social security wage thresholds to top-code the simulated data by the same amounts. This means we can treat the simulated data in the same way as the real data and do not have to interpolate top-coded values as in Card et al. (2013). Of employed workers’ wages 8.2% are subject to top-coding. Top-coding is more pertinent for high-skill workers, of whose wages 33.5% are top-coded. Wages of newly hired workers tend to be lower and only 6.7% are affected by top-coding.

We construct and match monthly moments by skill group for employment status transition rates, unemployment duration, the mean and standard deviation of the log of real re-entry daily wage, and correlations between log real re-entry wage and unemployment duration, and unemployment duration and firm rank by skill group. Monthly averages for each of these nine moments are shown for the estimation period from 2001 to 2005 in Appendix A.7.

In the estimation we match four rates of transitions between employment states. First, the job finding rate is defined as the monthly share of unemployed workers who find and accept a job. Second, the separation rate captures the monthly share of employed workers who exit into unemployment. We further match two moments that capture on-the-job moves to better and worse firms. Job-to-job promotions are defined as moves of employed workers to a new job with a higher ranked firm. The promotion rate is calculated as the monthly share of promotions out of all employed workers. Job-to-job demotions are moves of employed workers to a new job with a lower ranked firm. Firms are ranked based on their average 75th-percentile real wage for full-time employees during the period January 2001 to December 2005. We use the 75th-percentile average firm wage as a proxy for firm productivity, which Doniger (2015) finds to be a good predictor of firm value added in German worker-firm data. The job-to-job demotion rate is calculated as the monthly share of demotions out of all employed workers.

Unemployment duration is defined as the number of months a worker has spent in unemployment since his last employment spell, as recorded in the IAB Benefit Recipient History data. Attention is restricted to newly hired workers from unemployment instead of accounting for the
entire distribution of wages. This focus on re-entry wages is motivated by a number of factors. First, computing the entire distribution of wages is far more computationally expensive as a wage depends on five state variables \((x, y, z, y', z')\) rather than just three \((x, y, z)\) for re-entry wages. In addition, in order to compute the entire distribution one needs to keep track of all employment measures over time, rather than just the unemployed. Furthermore, the model has better empirical grounding as fewer re-entry wages are top-coded. Wages are reported as log real daily wages in Euros, and are deflated using the yearly Consumer Price Index from the German Federal Statistical Office. In the case of overlapping or multiple spell observations for an individual, we use the spell with the highest recorded wage.

As the monthly moment series exhibit marked seasonality for the month of January, we seasonally adjust all series to ensure that policy reforms are not mistaken with seasonal variation present in the data. For the seasonal adjustment we use the X-12-Arima program, which is a software developed by the US Census Bureau for seasonally adjusting time series data, by accounting for seasonal variation from January 1981 to December 2009. The inclusion of marginally employed workers in the SIAB data from 1999 onward causes a break in the wage series, which we level out by multiplying the pre-break series with the ratio of the 12-months post- to pre-break averages for the purpose of seasonal adjustment. To avoid negative values for seasonally adjusted transition rates, we take the log of transition moments, seasonally adjust, take the exponent of the seasonally adjusted series, and adjust so that the overall means sum to the means of the raw transition rates.

We choose not to include value added data which could feasibly be constructed by generating a measure of business volume net of inputs for workers linked to the German Establishment Panel in the Linked Employer-Employee Data, a companion dataset. Since we stratify our sample by worker skill, however, value added per worker would be difficult to calculate. We do not need value added information to identify the rent share parameter \(\beta\), as \(\beta\) is largely identified by the correlation between unemployment duration and wages among re-entrants. For example, in the limiting case of \(\beta = 0\), when wage is determined as in Postel-Vinay and Robin (2002). Given that the value of home production is orthogonal to worker type, in this setting starting wages are
decreasing in worker type. Workers of higher type are compensated with a larger option value of future employment. Since in every re-simulation lower unemployment duration is a noisy signal of worker type one needs $\beta$ to rationalize the negative correlation present empirically.

### 4.2 Parameterization

Time is measured in months and superscript $\tau \in \{1, 2, 3, 4\}$ denotes the period for which the parameter is applicable. Pre-reform values are denoted by $\tau = 1$, $\tau = 2$ are the parameter values after the first wave comprising the Hartz I and II laws, after Hartz III has taken effect $\tau = 3$; and $\tau = 4$ after Hartz IV is implemented. The absence of a $\tau$ superscript indicates a time-invariant parameter.

For the estimation it is necessary to make a number of parametric assumptions. Firstly, the discount rate $r$ is calibrated to be equivalent to a 5 percent annual rate. The productivity levels $x, y, z \in (0, 1)$ are drawn from uniform distributions. The assumption of uniformity of type is without loss of generality, and $x, y$ and $z$ are interpreted as ranks in their respective distributions. All variations in productivity occur through a production function taking the form:

$$f_k^{\tau}(x, y, z) = \exp\left( f_{0,k}^{\tau} \cdot \exp\left( f_{1,k}^{\tau} \Phi^{-1}(x) \right) \cdot \exp\left( f_{2,k}^{\tau} \Phi^{-1}(y) + f_{3,k}^{\tau} \Phi^{-1}(z) \right) \right)$$

$$- \exp\left( f_{4,k}^{\tau} \cdot \left| \exp\left( f_{1,k}^{\tau} \Phi^{-1}(x) \right) - \exp\left( f_{2,k}^{\tau} \Phi^{-1}(y) + f_{3,k}^{\tau} \Phi^{-1}(z) \right) \right| \right).$$  \hspace{1cm} (15)

This production function nests both the hierarchical and circle sorting models, pioneered with labor market frictions by [Shimer and Smith (2000)] and [Marimon and Zilibotti (1999)], respectively. $f_{0,k}^{\tau}$ is a scale parameter and $f_{1,k}^{\tau}, f_{2,k}^{\tau}$ and $f_{3,k}^{\tau}$ determine the variability in $x, y$ and $z$, and $\Phi^{-1}(\cdot)$ denotes the inverse of a standard normal distribution. The relative sizes of $f_{0,k}^{\tau}$ and $f_{4,k}^{\tau}$ capture the relative importance of the hierarchical and circle sorting models. A large (small) $f_{0,k}^{\tau}$ and small (large) $f_{4,k}^{\tau}$ implies that firms place more (less) weight on employing the best worker and care less (more) about getting the right worker for that particular job. The relative size of these parameters are likely to dictate the level of assortative matching in the economy.

The home production technology is assumed orthogonal to $x$, $b_k^{\tau}(x) = b_{0,k}^{\tau}$. The exogenous job destruction rates are given by $\delta_k^{\tau}$. Job offer arrival rates for the unemployed are assumed to be
time varying and given by $\lambda^T_{0,k}$, to reduce the dimensionality of the estimation. Offer arrival rates for employed individuals are assumed to be a constant factor $\kappa_k$ of the unemployed offer arrival rate, so that $\lambda^T_{1,k} \equiv \kappa_k \lambda^T_{0,k}$. $\kappa_k$ denotes the relative efficiency of search in employment relative to unemployment for skill group $k$.

The content of the specific Hartz reforms determine our choice of time varying and constant parameters. By means of this parameterization the Hartz reforms can affect the rates at which employed and unemployed workers receive job offers. As $\kappa$ is fixed, reforms affect the two arrival rates proportionally by construction. We allow the flow benefit of unemployment $b_0$ to vary with the reforms as the length and criteria for claiming unemployment insurance change. Finally, any endogenous changes adjustments of the type of firms and jobs in the economy are captured through changes to $f_2$ and $f_3$ respectively. Changes in the scale parameter $f_0$ reflect whether these changes are beneficial to the productive capabilities of firms. Exogenous job arrival and destruction rates are allowed to vary after every reform, which implies that we estimate four of each rate. We assume that the variability of firm and match type, and the scale parameter are only affected by the first wave of Hartz reforms, which primarily focused on labor demand factors. Finally, unemployment benefits are only influenced by the final wave of reforms. The vector of exogenous parameters to be estimated for skill group $k$ is denoted by $\theta_k$ and is defined in Section 4.4.

### 4.3 The Data Generating Process

The true data for skill group $k$, $X^0_k$, are a $T$ by $N$ matrix of the macroeconomic time series described in Section 4.1 where $T$ is the length of the time series and $N$ the number of moments targeted. We use moments for 60 months from January 2001 until December 2005, and assume that the true data $X^0_k$ is the sum of the model prediction $X^M(\theta_k)$, a deterministic trend $X^T_k$ and an irregular cyclical component $X^C_k$:

$$X^0_k = X^M(\theta_k) + X^T_k + X^C_k.$$  \hfill (16)

In our setting the trend and cyclical components represent the German economy independent of the reforms. In expectation the cyclical component is of mean zero and at the introduction
of the first wave of reforms, we set the trend equal to zero. Given this normalization the effects of the Hartz reforms can be uncovered from changes in $X^M(\theta_k)$ after subtracting other changes that would have happened in the absence of the reforms. The model and trend components are deterministic but the cyclical component is random. The cyclical component $X^C_k$ allows us to write down an analytical likelihood function, as for any $X^M(\theta_k)$ and $X^T_k$ there exists an $X^C_k$ to rationalize the true data $X^0_k$.

The trend and cyclical components are fitted from January 1993 until February 2002. This corresponds to the first inclusion of a representative East German sample in the data up to the formation of the Hartz Committee. The trend of each moment is assumed to be linear. Results for non-linear trends with higher order polynomials are qualitatively similar. We assume the cyclical component can be represented by the vector autoregressive process in equation (17), where $A_k$ is an $N \times N$ matrix of autoregressive coefficients for stratum $k$ and $\Sigma_k$ is an $N \times N$ symmetric variance-covariance matrix. These two objects are estimated by maximum likelihood and parameter estimates are reported in Supplementary Appendix B.3.

$$x^C_{t,k} = A_k x^C_{t-1,k} + \epsilon_{t,k} \quad \text{where, } \epsilon_{t,k} \sim N(0, \Sigma_k) \quad (17)$$

All moments and their forecasts over the policy horizon are presented in Appendix A.8. These forecast pictures serve two purposes. Firstly, they demonstrate the precision with which each moment is computed. The wider (narrower) the confidence bands on Figures A3, A4 and A5 the less (greater) precision the moment is predicted with and therefore the less (more) weight the estimator puts on attempting to fit a moment. Secondly, these forecasts give insight into the effects the Hartz reforms on the German labor market. Inspection of the figures suggest a marked change in the wage distribution compared with changes in the rate of employment. Across all skill groups the flow into employment falls below trend after the Hartz Committee is formed, and catches up by 2005. The flow out of employment remains broadly on trend for the low-skilled and falls slightly below for the higher skill groups. Back of the envelope calculations suggest a slight increase in employment, and by the end of the forecast time horizon none of these flows are significantly different from trend levels. The distribution of wages of workers newly hired from unemployment

29
exhibit large changes. The mean across all skill groups falls well below trend while the standard deviation exceeds the trend, in particular for more skilled workers. These wage trends suggest an important link between the Hartz reforms and wages, which has received little attention in previous studies.

4.4 The Likelihood Function

The likelihood function describes the likelihood of observing the innovative shocks required to rationalize the observed data. For a given $A_k$ and $\Sigma_k$ the vector of innovative shocks at time $t$ can be written as a function of the vector of structural parameters $\theta_k$ and an initial condition $\epsilon_{1,k}(\theta_k)$. We assume that $\epsilon_{1,k}(\theta_k)$ is equal to the initial deviation from trend, which has the advantage of keeping the likelihood expression simple and comparable to a method of moments estimator. An alternative initial condition is considered in Supplementary Appendix B.4 but the resulting differences in the value of the likelihood function are insignificant. All subsequent innovations are uncovered as follows, where lower case $\epsilon$ and $x$ represents the vector of all moments at time $t$.

$$
\epsilon_{t,k}(\theta_k) = x_{t,k}^0 - x_{t}^M - A \left[ x_{t-1,k}^0 - x_{t-1}^M - x_{t-1,k}^T \right]
$$

Since $\epsilon_{t,k}(\theta_k)$ is distributed following a multivariate normal distribution with mean zero and variance-covariance matrix $\Sigma_k$, we can write the likelihood function as follows:

$$
L(\epsilon_{1,k}(\theta_k), ..., \epsilon_{T,k}(\theta_k)) = \prod_{t=1}^{T} g(\epsilon_{t,k}(\theta_k)|\Sigma_k; \epsilon_{t-1,k}(\theta_k))
$$

$$
= (2\pi)^{-NT} |\Sigma_k|^{-T/2} \exp \left\{ -\frac{1}{2} \sum_{t=1}^{T} \epsilon_{t,k}(\theta_k)^T \Sigma_k^{-1} \epsilon_{t,k}(\theta_k) \right\},
$$

where $T$ is the length of the time series, $N$ is the number of series, $g(\cdot)$ is the probability density of a multivariate normal distribution, and $|\cdot|$ represents the determinant.

Instead of maximizing the likelihood, it proves convenient to minimize the log-likelihood function given by equation (18).

$$
\ell(\epsilon_{1,k}(\theta_k), ..., \epsilon_{T,k}(\theta_k)) = -2 \log L(\epsilon_{t,k}(\theta_k))
$$

$$
= NT \log(2\pi) + T \log |\Sigma_k| + \sum_{t=1}^{T} \epsilon_{t,k}(\theta_k)^T \Sigma_k^{-1} \epsilon_{t,k}(\theta_k)
$$

(18)
Since only the final term is dependent on $\theta_k$, minimizing the function is equivalent to minimizing the final term of the expression, which is the term we refer to in the remainder of the paper.

We make two refinements to improve the fit of the moments and to increase the functionality of the estimation procedure. Firstly, the likelihood function is highly nonlinear. One reason for this is the endogenous job destruction process. Recall, endogenous job destructions occur at the announcement or implementation of policy reform. The mass of no longer feasible matches, defined in equations (10) and (11) depends on the history of all other variables and can be large, so that they are only rationalized by improbably large draws of $\epsilon$. To smooth the likelihood function and to decrease the dimensionality of the problem, we fix the values of $\delta^k_\tau$ to match the job-to-unemployment flow in stable periods.\footnote{This is model consistent as in stable periods all job loss is exogenous. The theoretical counterpart of the mean job-to-unemployment transition rate for stable period $\tau$ amongst stratum $k$ is $\text{jtu}_k^\tau = 1 - \exp(-\delta^k_\tau)$. $\delta^k_\tau$ is fixed accordingly for all $k$ and $\tau$ prior to estimation.}

Secondly, the relative size of the variation in firm type $f_2$ and match type $f_3$ can be separately identified through the ratio of job-to-job mobility associated with movements up or down the firm ladder, as described in Proposition 2. Similarly, simulations of the model suggest that in order to match the second moments of wages we need to alter the total variability of $x$, $y$ and $z$. As we are not confident that the relative contributions of worker to firm and match contributions can be credibly identified, we set the sum of the match and firm type variabilities equal to unity, and estimate $f_1$ without constraints. Since the match and firm contributions enter symmetrically into the production function their relative size describes their relative importance in output.

$$f^2_{2,k} + f^3_{3,k} := 1 \text{ for all } (k, \tau)$$

The vector of exogenous parameters to be estimated, which for a skill group $k$ is $\theta_k \in \Theta \in \mathbb{R}^{14}$, is defined as:

$$\theta_k = (\lambda^4_{0,k}, \kappa, \delta^2_{0,k}, f^2_{0,k}, f^1_{1,k}, f^2_{2,k}, f^4_{4,k}, \beta_k).$$

The vector arrows denote that the respective parameters are either two or four dimensional objects that vary over time.
5 Results

This section presents the parameter estimates and the fit of the targeted dynamics of the model. We then simulate the model at steady-state before and after the reforms and evaluate the aggregate impacts of the policies, the relative importance of the successive waves, and the distributional impact on wages.

5.1 Parameter Estimates

The parameter estimates of the model are reported in Table 2, with asymptotic standard errors in the parentheses below the point estimates. For completeness, the table includes estimates of the job destruction parameters, which are calibrated. To ensure that the estimates represent global minima of the log-likelihood function \( \ell \) we initiate our estimation with parallel runs of a Metropolis-Hastings type algorithm, which is not as susceptible to stopping at local minima as a standard hill climbing algorithm. The numbered superscripts correspond to time separated by policy implementation.\(^6\)

The monthly job offer arrival rates are larger than in most previous studies, which is due to the frequency with which job offers are rejected. Back of the envelope calculations suggest for every offer accepted by an unemployed worker between two to four and a half offers are rejected on average, depending on the period and the skill group.\(^7\) The number of jobs not accepted increases with skill. Notably, the first wave of the reform reduces the number of job offers for all skill groups and with the exception of the final wave for the medium-skilled. All subsequent reforms increase the amount of job offers workers receive. Aggregating all reforms, workers receive less frequent job offers after the full implementation of the Hartz policies than before the reforms. The effect on the rate of exogenous job destruction is more ambiguous. The reforms leave the low-skilled in slightly less secure jobs and the medium- and high-skilled in somewhat more secure ones. The relative search intensity of the employed is approximately a fifth for all three groups, which implies that an

\(^6\)Specifically, the numbers denote (1) before the first wave, (2) after the first but before the second wave, (3) after the second but before the third wave, and (4) after the third and final wave.

\(^7\)For the calculation the average number of rejected offers is equal to the number of offers in a month, \( 1 - \exp(-\lambda_{i,k}) \), which is divided by the job finding rate minus one.
Table 2: Parameter estimates

<table>
<thead>
<tr>
<th></th>
<th>Low-skill</th>
<th></th>
<th>Medium-skill</th>
<th></th>
<th>High-skill</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\lambda_0^{(1)}$</td>
<td>$\lambda_0^{(2)}$</td>
<td>$\lambda_0^{(3)}$</td>
<td>$\lambda_0^{(4)}$</td>
<td>$\lambda_0^{(1)}$</td>
<td>$\lambda_0^{(2)}$</td>
<td>$\lambda_0^{(3)}$</td>
<td>$\lambda_0^{(4)}$</td>
</tr>
<tr>
<td></td>
<td>0.327</td>
<td>0.266</td>
<td>0.272</td>
<td>0.291</td>
<td>0.434</td>
<td>0.399</td>
<td>0.447</td>
<td>0.417</td>
</tr>
<tr>
<td></td>
<td>(0.0003)</td>
<td>(0.0003)</td>
<td>(0.0003)</td>
<td>(0.0003)</td>
<td>(0.0003)</td>
<td>(0.0002)</td>
<td>(0.0003)</td>
<td>(0.0003)</td>
</tr>
<tr>
<td></td>
<td>$\delta$</td>
<td></td>
<td></td>
<td></td>
<td>$\delta$</td>
<td></td>
<td>$\delta$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0057</td>
<td>0.0063</td>
<td>0.0060</td>
<td>0.0054</td>
<td>0.0127</td>
<td>0.0130</td>
<td>0.0127</td>
<td>0.0120</td>
</tr>
<tr>
<td></td>
<td>(0.0005)</td>
<td>(0.0007)</td>
<td>(0.0007)</td>
<td>(0.0007)</td>
<td>(0.0005)</td>
<td>(0.0007)</td>
<td>(0.0005)</td>
<td>(0.0007)</td>
</tr>
<tr>
<td></td>
<td>$\beta b_0^{(1)}$</td>
<td></td>
<td></td>
<td></td>
<td>$\beta b_0^{(2)}$</td>
<td></td>
<td>$\beta b_0^{(3)}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.287</td>
<td>5.92</td>
<td>1.09</td>
<td>0.209</td>
<td>0.255</td>
<td>14.00</td>
<td>6.71</td>
<td>0.199</td>
</tr>
<tr>
<td></td>
<td>(0.0003)</td>
<td>(0.0006)</td>
<td>(0.0001)</td>
<td>(0.0002)</td>
<td>(0.0002)</td>
<td>(0.0008)</td>
<td>(0.0004)</td>
<td>(0.0001)</td>
</tr>
<tr>
<td></td>
<td>$\kappa$</td>
<td></td>
<td></td>
<td></td>
<td>$\kappa$</td>
<td></td>
<td>$\kappa$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.242</td>
<td>13.07</td>
<td>8.65</td>
<td>0.203</td>
<td>0.242</td>
<td>13.07</td>
<td>8.65</td>
<td>0.203</td>
</tr>
<tr>
<td></td>
<td>(0.0003)</td>
<td>(0.02)</td>
<td>(0.01)</td>
<td>(0.0003)</td>
<td>(0.0003)</td>
<td>(0.02)</td>
<td>(0.01)</td>
<td>(0.0003)</td>
</tr>
<tr>
<td></td>
<td>Log-likelihood = 726</td>
<td></td>
<td></td>
<td></td>
<td>Log-likelihood = 1061</td>
<td></td>
<td>Log-likelihood = 758</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pseudo $R^2 = 0.67$</td>
<td></td>
<td></td>
<td></td>
<td>Pseudo $R^2 = 0.43$</td>
<td></td>
<td>Pseudo $R^2 = 0.52$</td>
<td></td>
</tr>
</tbody>
</table>

Note: All parameter estimates are given to three significant figures. Asymptotic standard errors are presented in the parenthesis and given to one significant figure. The log-likelihood reported is the value for the last term of equation (18). The pseudo log-likelihood with just the trend component.

We assume that the production function changes after the implementation of Hartz I/II, with results that are broadly consistent across all three skill strata. As a consequence of encouraging temporary work contracts, hiring subsidies and creating mini- and midi-jobs, the average productivity of a match is reduced. This effect is largest for the high-skilled, for whom average worker output falls by around 30%.[8] In addition to reducing the match productivity, the relative importance of inputs into the production process also changes. Before the reform, for medium- and low-skilled workers the match specific component is more consequential for total production than the firm they work for. For the high-skilled the match specific and the firm component are of equal importance.

---

[8]In this instance, by average we refer to the median, and imputing median values $x = 0.5$, $y = 0.5$ and $z = 0.5$ into the production function in equation (18) yields $f_k(0.5, 0.5, 0.5) = \exp(f_{k0})$. The mean production of a match is more complicated and depends on the distribution of worker, firm and matched types. The mean production of a match, however, falls by considerably less.
and $f_2^{(1)} = 0.5$. After the reform, for the medium- and low-skilled the match component becomes more important. For the high-skilled the opposite holds, for whom the firm component is now a more critical contributor to total production. Our interpretation is that for the two lower skilled strata Hartz I and II provide more sources by which individual jobs within firms can vary, and as a result a worker’s job type is more consequential than the firm that hires. For the high-skilled the effect moves in the opposite direction, but the type of mini- and midi-jobs created by the reforms are less likely to be performed by workers with university degrees.

For all skill types, an unemployed worker extracts approximately a quarter of the surplus from the firm. While this value is somewhat smaller than is often estimated in the literature, this bargaining power is compensated by later negotiations, when the worker can extract more rents from the firm after a period of employment. Finally, the value of home production is measured in real daily Euros. Hartz IV considerably reduced the generosity of unemployment benefit for some groups. The data show that mean daily real benefit received by the unemployed decreased from an average of 24.52 Euros between 2001-2004 to 21.73 Euros between 2005-2008. If we attribute this fall to Hartz IV the overall reduction is only 2.79 Euros per day, far less than the reduction predicted by the parameter estimates for all strata. One interpretation of this large fall is that in addition to decreasing the pecuniary generosity Hartz IV also generated a larger stigma associated with unemployment, and our estimates of $b_{0,k}$ can contain non-pecuniary factors.

5.2 The Fit

Estimating by maximum likelihood means that assessing the relative fit of the model to the data is more difficult than it would be in a moment matching exercise. As the value of the likelihood is not informative, we instead compute a pseudo $R^2$ based on McFadden’s $R^2$ for binary choice models. We compare the likelihood of our full model compared to if we just fit the trend component. We get a clear ordering in skill group of how well the model fits the data. The magnitude of the pseudo $R^2$s are encouraging. Although not directly comparable, McFadden reports in [McFadden (1978)] that the pseudo $R^2$ tends to “be considerably lower than those of the [standard] $R^2$ index […]” or
example, values of 0.2 to 0.4 for [the pseudo $R^2$] represent excellent fit.”

In structural models one should be cautious in presenting the fit of the model, as a more pressing question is whether the data generating process is correctly specified - something that we have put a great deal of structure on. To assess this we compare the joint distributions of realized shocks to rationalize the data with the sampling distribution that the shocks are drawn from. When these two distributions broadly match, it is likely that the model generates the dynamics we observe empirically. These comparisons are presented in the Figures in Supplementary Appendix B.5. The diagonal shows the marginal distributions of the shocks to each series and the off diagonal represents pairwise joint distributions. Realized shocks are plotted in red and random draws from the sampling distribution are in blue. The ellipses are 95% confidence intervals, and contain 95% of all draws. The Figures indicate that the innovative shocks are credibly drawn from their specified distributions, implying that in order to fit the data the model does not rely on unusual draws from the shock distributions. There is no apparent consistent pattern across skill groups of moments that the model has difficulty in replicating. The low-skilled appear to fit the data best with the realized shocks and the sampling distributions largely coinciding. The correlation between firm rank and unemployment duration exhibits the least fit for the medium-skilled, as the realized shocks appear drawn with a lower mean than the sampling density suggests. Finally, the high-skilled appear to fit the data least well, requiring lower draws than the sampling density for the standard deviation of log wages among re-entrants and higher draws for the two measures of job-to-job mobility.

Although the estimation procedure is not directly targeting the best fit of the macroeconomic time series we construct, it is important that the simulations match their empirical counterparts closely. If we assume that the cyclical component is not persistent, then our likelihood function becomes identical to a method of moments estimator with $T \times N$ independent moments. The simulated series are displayed in Figures A6, A7 and A8 in Appendix A.9. The solid black line represents the data and the blue line represents the simulation. The shaded blue area is the 95% confidence interval obtained by repeated redrawing of the series of shocks. In addition to the moments included in the estimation, we also present the job separation series, which were omitted.
Table 3: Combined impact of the Hartz reforms

<table>
<thead>
<tr>
<th></th>
<th>Pre-reform</th>
<th>Post-reform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unemployment rate</td>
<td>12.1%</td>
<td>11.3%</td>
</tr>
<tr>
<td>Mean of daily wage (Euros)</td>
<td>135.17</td>
<td>123.85</td>
</tr>
</tbody>
</table>

from the estimation. The figures display good fit, in particular for moments that involve wage data.

5.3 Simulations

The persistence of employment and wages makes inference about the long run impact of the Hartz reforms difficult.\textsuperscript{9} We therefore apply our structural model to determine the long run effect on employment by computing the steady-state wage distribution, evaluated at the point estimates of the parameter estimates. To compute the steady-state of the wage distribution we impose a stricter condition than was used for estimation. Previously, for $t$ in a steady-state we assumed that the measure $e_t(x, y, z)$ was fixed. Since wages can potentially depend on the best outside offer a worker receives while in employment, the new stricter steady-state condition is that for $t$ in steady-state $e_t(x, y, z, y', z')$ is fixed, where $(y', z')$ is the best outside offer pair a worker receives. This stricter steady-state condition is derived in Appendix A.10.

5.3.1 Aggregate Outcomes

We investigate the long run impact of the three reform waves jointly on wages and employment. To address this question we compare employment and wages in two steady-states, one for the initial values of the structural parameters and the other one for the values that the structural parameters take after the final reform wave implementation. Table 3 presents the impact directly attributable to the Hartz reforms before and after the policies are implemented. The sample is weighted according to the relative sizes of the three skill groups given in Table 1.

One main result is that the Hartz reforms expanded employment by around 0.8 percentage

\textsuperscript{9}In the German context, persistence of employment and wages is, for example, documented in [Hartung et al. 2015].
points, so that the post-reform unemployment rate decreased to 11.3%. Comparing pre- and post-
reform wages shows that this employment expansion came at the cost of an 8.4% reduction in wages, 
from a daily mean wage of 135.17 Euros to 123.85 Euros. The overall reduction in unemployment 
is of similar magnitude as that of [Fahr and Sunde (2009)], who suggest the reforms were associated 
with a 5-10% increase in the job finding probability. [Hertweck and Sigrist (2013)], however, find an 
effect three times this size. The pronounced effect of the reforms on wages highlights the trade-off 
labor market policymakers face between unemployment and wages.

The mean wages reported in Table 3 are higher than the mean sample wage of 74.12 Euros 
reported in Section 4.1. Firstly, this is the case because the simulations are not top-coded, unlike 
our estimation and the data. If one were to top-code simulated wages as is done in the data, the 
pre-reform mean wage drops to 97.51 Euros per day. The reason for the remaining overestimation 
is that we only use the wages of those entering employment from unemployment to identify the 
parameters of our model. In effect we therefore make use of the model to extrapolate to the overall 
earnage distribution.

5.3.2 Individual Hartz Reforms

Our approach allows us to examine the impact of each reform separately, as well as of pairs of reform 
waves. The impact of the first wave and the first and second waves jointly can be uncovered without 
any further parametric assumptions. Since we estimate the vector of structural parameters pre- and 
post-reform in both instances, it is straightforward to simulate the steady-state economy imposing 
these changes. Assessing the other waves in isolation requires parameterizing the evolution of the 
structural parameters. We assume that policies affect the structural parameters in a proportional 
way, where $\pi$ is a vector capturing the proportional impact of a specific wave or of a pair of waves. 
Under this assumption we can construct a vector of structural parameters as if a latter wave was 
implemented in the initial economy:

$$\theta_{\text{post-reform}} = \pi \times \theta_{\text{pre-reform}}$$

Table 4 shows the aggregate effects on employment and wages of individual reforms. The
Table 4: Combined impact of reforms on employment and wages

<table>
<thead>
<tr>
<th>Percentage point change in employment rate</th>
<th>Hartz I/II</th>
<th>Hartz III</th>
<th>Hartz IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hartz I/II</td>
<td>0.62% ↓</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hartz III</td>
<td>0.31% ↓</td>
<td>0.42% ↑</td>
<td>-</td>
</tr>
<tr>
<td>Hartz IV</td>
<td>0.89% ↑</td>
<td>1.22% ↑</td>
<td>0.76% ↑</td>
</tr>
<tr>
<td>Combined impact:</td>
<td>0.80% ↑</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percentage change in mean wage</th>
<th>Hartz I/II</th>
<th>Hartz III</th>
<th>Hartz IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hartz I/II</td>
<td>10.2% ↓</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hartz III</td>
<td>6.9% ↓</td>
<td>3.8% ↑</td>
<td>-</td>
</tr>
<tr>
<td>Hartz IV</td>
<td>7.7% ↓</td>
<td>2.4% ↑</td>
<td>2.0% ↓</td>
</tr>
<tr>
<td>Combined impact:</td>
<td>8.4% ↓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

diagonal elements depict a reform wave in isolation, and the off-diagonal elements represent the implementation of pairs of reforms. If policymakers were only concerned with employment and wage levels, it would be preferable not to implement the first wave of reforms. Implementing Hartz III and IV only would increase employment by a third more than the overall value, with wages increasing by 2.4% rather than falling by 8.4%. Hartz III, the second wave of reforms, that restructured the Federal Employment Agency, is unambiguously successful, and implementing Hartz III in isolation has a positive impact on both employment and wages. These results follow from our parameter estimates. The effect of the second wave of increasing the job finding rate and reducing the job destruction rate for all skills, leads to an increase in employment. Through the job ladder mechanism and re-negotiations, the second wave also raises wages. By contrast, we expect the first wave to reduce both employment and wages as Hartz I/II has a negative effect on the job finding and separations rates coupled with a reduction in the scale parameters of production. Hartz IV, the final and most controversial reform wave increases the job offer rate and decreases the separation rate, with some variation according to worker skill. Hart IV also reduces the flow benefit received in unemployment considerably, thereby providing further expansion to employment as workers accept a greater proportion of their job offers. At the same time, Hartz IV depresses wages by reducing a worker’s outside option in wage negotiations. As shown in Table 4, this outside option effect dominates any wage gains associated with longer job tenure. If one were to implement only Hartz IV, this would lead to a 0.76 percentage point increase in employment associated with a 2% fall in mean wages. Our analysis quantifies the trade-off between a high wage - low employment
economy and a low wage - high employment alternative. Policies that implement more stringent rules with respect to unemployment benefits need to evaluate this trade-off explicitly.

5.3.3 Wage Decomposition

The simulations underline the reduction in wages as a result of the Hartz reforms. We further investigate this change in the distribution of wages by decomposing wage variation pre- and post-reform. This effort extends the wage decomposition exercises in Postel-Vinay and Robin (2002) and Bagger and Lentz (2014). First, we simulate the model in two steady-states. The initial steady-state takes place before the announcement of the Hartz reforms and the second steady-state is realized after the implementation of all four reforms. We simulate the model for same number of individuals as in the data. For each simulated individual $i$ we compute his employment status, his wage, his permanent productivity type, his firm’s type, his match productivity, the type of firm and match quality who provide the best counteroffer if applicable, and finally the skill strata he belongs to. Using ordinary least squares the log of wages for individual $i$ are projected on to a constant $\hat{\rho}_0$, a worker component $\tilde{x}_i$, a firm component $\tilde{y}_i$, a match component $\tilde{z}_i$, and a frictional component $\tilde{f}_i$. Further details of the wage projection are provided in Appendix A.11.

$$\log w_i = \hat{\rho}_0 + \tilde{x}_i + \tilde{y}_i + \tilde{z}_i + \tilde{f}_i$$

Using Eve’s Law we can separate the total variance into within and between firm components. In order to be in line with the empirical literature, we decompose by firm type.

$$\text{Var}(\log w_i) = \text{Var}(E[\tilde{x}_i + \tilde{y}_i + \tilde{z}_i + \tilde{f}_i|\tilde{y}_i]) + E(\text{Var}[\tilde{x}_i + \tilde{y}_i + \tilde{z}_i + \tilde{f}_i|\tilde{y}_i])$$

Expanding and rearranging, we decompose the relevant sizes of firm, worker, match, frictional and sorting effects. We combine all sorting effects in a single measure, because the relative size of each sorting component varies greatly according to the object we initially difference between. The worker, match and frictional components of total variance are the expected variation of each of these factors conditional on firm type. The firm component includes the expected level of outside
offers within a firm, as according to structural model, these will systematically vary across firms.

\[
\text{Var}(\hat{\log} w_i) = \text{Var}(\hat{y}_i) + \text{Var}(E[\hat{f}_i|\hat{y}_i]) + 2\text{Cov}(\hat{y}_i, E[\hat{f}_i|\hat{y}_i]) \\
+ \text{Var}(E[\hat{x}_i|\hat{y}_i]) + \text{Var}(E[\hat{z}_i|\hat{y}_i]) + \text{Var}(E[\hat{\tilde{z}}_i|\hat{y}_i]) \\
+ 2\text{Cov}(E[\hat{x}_i|\hat{y}_i], E[\hat{\tilde{z}}_i|\hat{y}_i]) \\
+ 2\text{Cov}(E[\hat{x}_i|\hat{y}_i], E[\hat{z}_i|\hat{y}_i]) + 2\text{Cov}(E[\hat{x}_i, E[\hat{\tilde{z}}_i|\hat{y}_i]]) \\
+ 2\text{Cov}(E[\hat{x}_i, E[\hat{z}_i|\hat{y}_i]]) + 2E[\text{Cov}(\hat{x}_i, \hat{\tilde{z}}_i|\hat{y}_i)] \\
+ 2E[\text{Cov}(\hat{x}_i, \hat{z}_i|\hat{y}_i)]
\]

Table 5 presents the proportion of wage variation that is explained by each of the five effects pre- and post-reform.

### Table 5: Wage decomposition

<table>
<thead>
<tr>
<th></th>
<th>% of Var(\hat{\log} w_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-reform</td>
</tr>
<tr>
<td>Worker effect</td>
<td>80.4%</td>
</tr>
<tr>
<td>Firm effect</td>
<td>3.8%</td>
</tr>
<tr>
<td>Match effect</td>
<td>2.8%</td>
</tr>
<tr>
<td>Frictional effect</td>
<td>4.8%</td>
</tr>
<tr>
<td>Sorting effect</td>
<td>8.2%</td>
</tr>
</tbody>
</table>

Firstly, the large explanatory power of the worker effect is notable. Approximately 80% of wage variation are due to differences in worker ability, which is greater than the proportion typically found in wage decomposition exercises. In a similar decomposition Card et al. (2013) show that person effects (observed and unobserved) explain 78% of the non-residual German wage variation from 1985 to 1991 and 57% from 2002 to 2009. We may be overestimating the importance of the worker effect as a result of our wage projection that assigns all differences in observable worker skill to worker differences. By construction this does not allow firm or match types to differ systematically across strata. As a result, we emphasize the direction of changes of the pre- and post-reform effects in Table 5 more than their magnitudes.
The decomposition shows that the four Hartz reforms structurally changed the sources of wage variation. Firstly, there is a small shift in increased importance for match relative to firm effects. As a consequence of Hartz I/II more emphasis is put on the match rather than skill component for the low- and medium-skilled. The wage decomposition in Table shows how this change in production translates into workers’ wages. A larger and subtle consequence is the shift in importance from sorting to frictional wage dispersion. The increase in the frictional effect is a consequence of longer job tenures, as separation rates fall for all but the lowest skilled and there is a greater volume of acceptable offers. This means, in a given employment spell, more workers have received offers that are either good enough to put upward pressure on their current wage, or so good that they move to new firms, using their old employer as an outside option in wage bargaining. The decrease in the contribution of sorting to wage variation is likely to be a result of workers becoming less picky about firm and match types because of lower outside options in unemployment, driven primarily by the final Hartz reform wave. As a result, workers are willing to match with less productive jobs and the overall sorting pattern is closer to a random assignment.

6 Conclusion

This paper develops an approach for evaluating comprehensive labor market reforms. We construct and estimate a model of the labor market with search frictions, heterogeneity and complementarities in production. These labor market features are critical to understanding the impact of labor market policy changes in many contexts, where detailed matched worker-firm data are available. We implement this approach by evaluating the Hartz labor market reforms in Germany in the early 2000s. Similarly, one could adapt our framework to evaluate structural labor market reforms in other contexts, such as those introduced by the Spanish government in 2012.

In our setting, the Hartz labor market reform laws are treated as shocks to the structural parameters, which are fully anticipated by forward looking agents. To analyze the effects of the German Hartz reforms the model is estimated by maximum likelihood estimation with matched worker-firm data. Identification is achieved by exploiting the off steady-state dynamics of the model.
The results of our evaluation show that the Hartz reforms reduced unemployment but to a smaller extent than suggested by previous studies. We also find that this reduction in unemployment was associated with a significant reduction in real wages. Our results further indicate that the reforms could have been more beneficial for employment and wage growth by not adopting the reform wave that introduced mini- and midi-jobs. Lastly, we document a shift in the drivers behind wage variation as a direct consequence of the labor market reforms in Germany. In the post-reform labor market, frictional wage dispersion and match specific variation become more important, while the effects of sorting and variation in firm type decreased.

Our paper shows that a comprehensive approach to evaluating labor market policy changes provides insights that are not easily obtained in reduced form assessments of particular aspects of a reform, or with calibrated macro models. The evaluation approach we propose makes use of detailed administrative data on workers and firms, which have recently become available for an increasing number of countries. Detailed data thus enable a careful assessment of the trade-off between employment and wage growth that is inherent in many labor market policy choices.
References


A Appendix

A.1 Value Functions

The present discounted value of an unemployed worker of productivity \( x \) is equal to \( b_t(x) \), the flow utility of unemployment, the option value of employment and the associated change if a policy is implemented:

\[
U_t(x) = b_t(x) + \lambda_0, t \int \int_{y', z' \in \mathcal{M}_{0,t}(x)} \left[ W_t(\phi_{0,t}(x, y', z'), x, y', z') - U_t(x) \right] v(y') \gamma(z') dy' dz' + \eta \left[ U_{t'}(x) - U_t(x) \right]
\]

Using the identity given by equation (2), the above simplifies to:

\[
U_t(x) = b_t(x) + \beta \lambda_0, t \int \int_{y', z' \in \mathcal{M}_{0,t}(x)} S_t(x, y', z') v(y') \gamma(z') dy' dz' + \eta \left[ U_{t'}(x) - U_t(x) \right]
\]

The value function for an employed worker of productivity \( z \) earning a wage \( w \) at time \( t \), is more cumbersome:

\[
W_t(w, x, y, z) = w + \delta_t [U_t(x) - W_t(w, x, y, z)]
\]

\[
+ \lambda_{1,t} \int \int_{y', z' \in \mathcal{M}_{1,t}(x, y, z)} \left[ W_t(\phi_{0,t}(x, y', z'), x, y', z') - W_t(w, x, y, z) \right] v(y') \gamma(z') dy' dz'
\]

\[
+ \lambda_{1,t} \int \int_{y', z' \in \mathcal{M}_{1,1,t}(x, y, z)} \left[ W_t(\phi_{1,t}(x, y', y, z), x, y', z') - W_t(w, x, y, z) \right] v(y') \gamma(z') dy' dz'
\]

\[
+ \lambda_{1,t} \int \int_{y', z' \in \mathcal{M}_{2,e}(w, x, y, z)} \left[ W_t(\phi_{1,t}(x, y, z, y', z'), x, y, z') - W_t(w, x, y, z) \right] v(y') \gamma(z') dy' dz'
\]

\[
+ \eta \left[ \{ \theta_{t'} \in \mathcal{N}_{0,t'}(x, y, z) \} U_{t'}(x) + \{ \theta_{t'} \in \mathcal{N}_{1,t'}(w, x, y, z) \} W_{t'}(w, x, y, z) + \{ \theta_{t'} \in \mathcal{N}_{2,t'}(w, x, y, z) \} W_{t'}(\phi_{0,t'}(x, y, z), x, y, z) + \{ \theta_{t'} \in \mathcal{N}_{3,t'}(w, x, y, z) \} W_{t'}(\phi_{1,t'}(x, y, z, y, z), x, y, z) - W_t(w, x, y, z) \right]
\]

The four option values in the above expression are unemployment risk, finding a much better job and using unemployment as a threat point, finding a better job and using the current employer as a threat point, and promotion within one’s current employer. Unemployment occurs if a match is exogenously dissolved, which happens at the Poisson rate \( \delta_t \). After a worker meets a new firm, depending on the draw of \( y' \) and \( z' \), the worker may move if the pair falls in the set \( \mathcal{M}_{1,t}(x, y, z) \). If
the new job is sufficiently better than the current one \((y', z') \in \mathcal{M}_{10,t}(x, y, z)\) then unemployment is used as a threat point. If the draw is a small improvement, and \((y', z') \in \mathcal{M}_{11,t}(x, y, z)\), then the worker uses his current employer as a threat point in Bertrand competition. Finally, a worker gets a within firm promotion if his new offer \((y', z') \in \mathcal{M}_{2,t}(w, x, y, z)\). All these sets are formally defined in Section 3.3.

In addition to the option value of employment there is a possibility that labor market reforms change the employment value. These reforms occur at a Poisson rate \(\eta_t\) and their implications depend on the way in which matched agents re-negotiate their employment contract. The exact re-negotiation mechanism of our benchmark model is outlined in Section 3.4. To demonstrate that other wage re-negotiation mechanisms can be accommodated we write the new re-negotiated wage in time \(t'\) as \(n_{t'}(w, x, y, z)\). We impose three regularity conditions on \(n_{t'}(w, x, y, z)\) that re-negotiation adheres to.

**Neither party wants to dissolve the match:** The firm’s value function is greater than or equal to zero, its outside option.

\[
\Pi_{t'}(n_{t'}(w, x, y, z), x, y, z) \geq 0
\]

Similarly for a worker, the value of the match must at least match the value obtained in unemployment.

\[
W_{t'}(n_{t'}(w, x, y, z), x, y, z) \geq U_{t'}(x)
\]

**Transferable utility:** The wage does not affect the size of the surplus.

\[
W_{t'}(n_{t'}(w, x, y, z), x, y, z) - U_{t}(x) + \Pi_{t}(n_{t'}(w, x, y, z), x, y, z) = S_{t}(x, y, z)
\]

If one subtracts the value of unemployment from the value of employment as defined previously and applies the identity given by equation (3), then the surplus generated for a worker earning a wage \(w\) of productivity \(x\) in a firm of productivity \(y\) with match specific productivity \(z\) at time \(t\) is derived as the following expression. The worker surplus is defined as the value of employment net
of the worker’s outside option, unemployment.

\[(r + \delta_t + \eta_t)[W_i(w, x, y, z) - U_i(x)] = w - b_t(x)\]

\[+ \lambda_{1,t} \int \int_{y',z' \in M_{10,t}(x,y,z)} [\beta S_t(x, y', z') + U_t(x) - W_t(w, x, y, z)] v(y') \gamma(z') dy' dz'\]

\[+ \lambda_{1,t} \int \int_{y',z' \in M_{11,t}(x,y,z)} [S_t(x, y, z) + U_t(x) - W_t(w, x, y, z)] v(y') \gamma(z') dy' dz'\]

\[+ \lambda_{1,t} \int \int_{y',z' \in M_{21,t}(w,x,y,z)} [S_t(x, y', z') + U_t(x) - W_t(w, x, y, z)] v(y') \gamma(z') dy' dz'\]

\[- \beta \lambda_{0,t} \int \int_{y',z' \in M_{01,t}(x)} S_t(x, y', z') v(y') \gamma(z') dy' dz'\]

\[+ \eta_t 1\{\theta_t' \notin N_{0,t'}(x, y, z)\} [W_{t'}(n_{t'}(w, x, y, z), x, y, z) - U_{t'}(x)]\]

Turning to the firm, the value for a firm of productivity \(y\), hiring a worker of productivity \(x\) at a wage rate \(w\) with a match specific productivity of \(z\) at time \(t\) is given by the function \(\Pi_t(w, x, y, z)\).

\[r \Pi_t(w, x, y, z) = f_t(x, y, z) - w + \delta_t[0 - \Pi_t(w, x, y, z)]\]

\[+ \lambda_{1,t} \int \int_{y',z' \in M_{11,t}(x,y,z)} [0 - \Pi_t(w, x, y, z)] v(y') \gamma(z') dy' dz'\]

\[+ \lambda_{1,t} \int \int_{y',z' \in M_{21,t}(w,x,y,z)} [\Pi_t(\phi_{1,t}(x, y, z, y', z'), x, y, z) - \Pi_t(w, x, y, z)] v(y') \gamma(z') dy' dz'\]

\[+ \eta_t 1\{\theta_t' \notin N_{0,t'}(x, y, z)\} [0 - \Pi_t(w, x, y, z)]\]

\[+ \eta_t 1\{\theta_t' \notin N_{0,t'}(x, y, z)\} [\Pi_{t'}(n_{t'}(w, x, y, z), x, y, z) - \Pi_t(w, x, y, z)]\]

The value function for the firm is analogous to that of the worker with a few exceptions. The flow value of the match is the total output produced \(f_t(x, y, z)\) net of the wage paid \(w\), the outside option of the firm is zero and not unemployment, and the firm does not care about the terms of the worker’s next job, just if the worker leaves. Summing the above two expressions and applying the identity in equation \([1]\) yields the total surplus generated by a match of a worker with ability \(x\) and a firm of productivity \(y\) with a match specific productivity of \(z\) at time \(t\).

\[(r + \delta_t + \eta_t)S_t(w, x, y, z) = f_t(x, y, z) - b_t(x) - \beta \lambda_{0,t} \int \int_{y',z' \in M_{01,t}(x)} S_t(x, y', z') v(y') \gamma(z') dy' dz'\]

\[+ \lambda_{1,t} \int \int_{y',z' \in M_{10,t}(x,y,z)} [\beta S_t(x, y', z') - S_t(x, y, z)] v(y') \gamma(z') dy' dz'\]

\[+ \eta_t 1\{\theta_t' \notin N_{0,t'}(x, y, z)\} [W_{t'}(n_{t'}(w, x, y, z), x, y, z) - U_{t'}(x) + \Pi_{t'}(n_{t'}(w, x, y, z), x, y, z)]\]
Transferable utility means the final term is the surplus in period $t'$. Inspection of the sets $M_{0,t}(x)$, $M_{10,t}(x)$, and $N_{0,t'}(x)$ reveals the surplus equation can be expressed in a simpler way. Following the notation of Lise and Robin (2016) we denote $A := \max\{A, 0\}$. The surplus is independent of the wage rate, which validates the assumption of transferable utility.

Given the regularity condition imposed on $f$ that $\lim_{z \to \bar{z}} f_t(x, y, z) = \infty$, and taking the limit of the right hand side of equation (4) implies

\[
(r + \delta_t + \eta_t)S_t(x, y, z) = f_t(x, y, z) - b_t(x) - \beta \lambda_{0,t} \int \int S_t(x, y', z')^+ v(y') \gamma(z') dy'dz' + \lambda_{1,t} \int \int \left[ \beta S_t(x, y', z') - S_t(x, y, z) \right]^+ v(y') \gamma(z') dy'dz' + \eta_t S'_t(x, y, z)^+
\]

A.2 Proofs of Lemma 1, Proposition 1 and Lemma 2

A.2.1 Lemma 1

Given the regularity condition imposed on $f$ that $\lim_{z \to \bar{z}} f_t(x, y, z) = \infty$, and taking the limit of the right hand side of equation (4) implies

\[
\lim_{z \to \bar{z}} ((r + \delta_t + \eta_t)S_t(x, y, z)) = \infty + C_t(x) + D_t(x, y) + E_t(x, y)
\]

where

\[
C_t(x) = -b_t(x) - \beta \lambda_{0,t} \int \int S_t(x, y', z')^+ v(y') \gamma(z') dy'dz'
\]

and

\[
D_t(x, y) = \lambda_{1,t} \lim_{z \to \bar{z}} \left( \int_{\bar{y}}^{\bar{z}} \int_{\bar{z}}^{\bar{z}} \left\{ \beta S_t(x, y', z') - S_t(x, y, z) \right\}^+ \gamma(z') dz' v(y') dy' \right)
\]

and

\[
E_t(x, y) = \eta_t \lim_{z \to \bar{z}} \left( \eta_t S'_t(x, y, z)^+ \right)
\]

$C_t(x)$ is a constant for given $x$, and thus the limit properties of $S_t(x, y, z)$ are independent of this term. Further, it is assumed that $S_t : (\bar{x}, \bar{y}) \times (\bar{y}, \bar{z}) \times (\bar{z}, \bar{z}) \to \mathbb{R}$.

(i) Assume $\lim_{z \to \bar{z}} S_t(x, y, z)$ is equal to a finite number. Then $D_t(x, y)$ would equal a finite number. $E_t(x, y) = \infty$ for $\lim_{z \to \bar{z}} S'_t(x, y, z) = \infty$ and $E_t(x, y)$ is equal to a finite number in all other situations. Thus, irrespective of the feasible value that $E_t(x, y)$ takes, $\lim_{z \to \bar{z}} S_t(x, y, z) = \infty$, which is inconsistent with our assumption.

(ii) Assume $\lim_{z \to \bar{z}} S_t(x, y, z) = -\infty$. Then $D_t(x, y) = \infty$ and $E_t(x, y) = \infty$ for $\lim_{z \to \bar{z}} S'_t(x, y, z) = \infty$ and $E_t(x, y)$ is equal to a finite number in all other situations. Again, $\lim_{z \to \bar{z}} S_t(x, y, z) = \infty$.

The term $E_t(x, y)$ is indexed by $t$, as by definition $t'$ is the period that arrives immediately after $t$. 49
\(\infty\), which is inconsistent with our assumption.

(iii) Finally, assume \(\lim_{z \to \infty} S_t(x, y, z) = \infty\). Then \(D_t(x, y) = \infty\) for \(\lim_{z \to \infty} S_t'(x, y, z) = \infty\) and \(E_t(x, y)\) is equal to a finite number in all other situations. Thus, irrespective of the feasible value that \(E_t(x, y)\) takes, \(\lim_{z \to \infty} S_t(x, y, z) = \infty\), which is consistent with our assumption. \(Q.E.D.\)

### A.2.2 Proposition 1

To prove Proposition 1, it is enough to show that for any \((x, y)\) there is a \(z\) such that \(S_t(x, y, z) \geq 0\).

For fixed \(x\) and \(y\), the fact that \(S_t(x, y, z)\) is positive translates to the condition that:

\[
\begin{align*}
  f_t(x, y, z) + N_1(z) + N_2(z) & \geq N_0 \\
                               & \quad \text{where} \quad N_0 = b_t(x) + \beta \lambda_{0,t} E_{y', z'} \left[ \max \left\{ S_t(x, y', z'), 0 \right\} \right] \\
                               & \quad \text{and} \quad N_1(z) = \lambda_{1,t} E_{y', z'} \left[ \max \left\{ \beta S_t(x, y', z') - S_t(x, y, z), 0 \right\} \right] \\
                               & \quad \text{and} \quad N_2(z) = \eta_t S_t'(x, y, z)
\end{align*}
\]

As \(z \to \infty\), \(f_t(x, y, z) \to \infty\) and from Lemma 1 as \(z \to \infty\), \(S_t(x, y, z) \to \infty\) which means \(N_1(z) \to 0\) and \(N_2(z) \to \infty\). Thus collectively, the left hand side of the above expression tends to infinity as \(z\) tends to its limit and the right hand side is, for fixed \(x\), constant. Therefore there is a \(z\) which satisfies \(f_t(x, y, z) + N_1(z) + N_2(z) > N_0\). This \(z\) will satisfy \(S_t(x, y, z) \geq 0\). \(Q.E.D.\)

### A.2.3 Lemma 2

For fixed \(x, y, y', z'\), the condition \(S_t(x, y, z) > S_t(x, y', z')\) can be translated into:

\[
\begin{align*}
  f_t(x, y, z) + N_1(z) + N_2(z) & > (r + \delta_t + \eta_t) S_t(x, y', z') + N_0 \\
  & \quad \text{where} \quad N_0, N_1(z) \text{ and } N_2(z) \text{ are defined as before.}
\end{align*}
\]

Only the left hand side varies with \(z\). From Lemma 1 as \(z\) tends to \(\infty\), the left hand side tends to infinity. Therefore there is a \(z\) which satisfies \(f_t(x, y, z) + N_1(z) + N_2(z) > (r + \delta_t + \eta_t) S_t(x, y, z) + N_0\). This \(z\) will satisfy \(S_t(x, y, z) > S_t(x, y', z')\). \(Q.E.D.\)
A.3 New Entrant’s Wages

The wage a worker receives at time \( t \), when hired from unemployment, is such that he takes a share \( \beta \) of the total surplus generated from the match.

\[
(r + \delta_t + \eta_t) (W_t(\phi_{0,t}(x, y, z), y, z) - U_t(x)) = (r + \delta_t + \eta_t) \beta S_t(x, y, z)
\]

Computing the option value of employment, derived in Section A.1, evaluated at \( w = \phi_{0,t}(x, y, z) \) gives:

\[
(r + \delta_t + \eta_t) (W_t(\phi_{0,t}(x, y, z), y, z) - U_t(x)) = \phi_{0,t}(x, y, z) - b_t(x)
\]

By applying the wage identities defined by equations (2) and (3), we get:

\[
(r + \delta_t + \eta_t) \beta S_t(x, y, z) = \phi_{0,t}(x, y, z)
\]

\[
+ \lambda_{1,t} \beta \int_{y', z' \in \mathcal{M}_{10,t}(x, y, z)} [S_t(x, y', z') - S_t(x, y, z)] v(y') \gamma(z') dy'dz'
\]

\[
+ \lambda_{1,t} (1 - \beta) S_t(x, y, z) \int_{y', z' \in \mathcal{M}_{11,t}(x, y, z)} v(y') \gamma(z') dy'dz'
\]

\[
+ \lambda_{1,t} \int_{y', z' \in \mathcal{M}_{2,t}(\phi_{0,t}(x, y, z), x, y, z)} [S_t(x, y', z') - \beta S_t(x, y, z)] v(y') \gamma(z') dy'dz'
\]

\[
- b_t(x) - \beta \lambda_{0,t} \int_{y', z' \in \mathcal{M}_{0,t}(x)} S_t(x, y', z') v(y') \gamma(z') dy'dz'
\]

\[
+ \eta_t 1{\theta' \notin \mathcal{N}_{0,t'}(x, y, z)} \{ W_{t'}(\phi_{0,t'}(x, y, z), x, y, z) - U_{t'}(x) \}
\]

By applying the wage identities defined by equations (2) and (3), we get:
Substituting out the common terms in the above expression and in equation (4), which defines the surplus, and rearranging yields:

\[
\phi_{0,t}(x, y, z) = f_t(x, y, z) - (1 - \beta)(r + \delta_t + \eta_t)S_t(x, y, z) \\
- (1 - \beta)\lambda_{1,t}S_t(x, y, z)\int \int_{y', z' \in M_{10,1}(x, y, z)} v(y')\gamma(z')dy'dz' \\
- (1 - \beta)\lambda_{1,t}S_t(x, y, z)\int \int_{y', z' \in M_{11,1}(x, y, z)} v(y')\gamma(z')dy'dz' \\
- \lambda_{1,t}\int \int_{y', z' \in M_{2,t}(\phi_{0,t}(x, y, z), x, y, z)} [S_t(x, y', z') - \beta S_t(x, y, z)]v(y')\gamma(z')dy'dz' \\
+ \eta_t(1 - \beta)1\{\theta_t \notin N_{0,\nu}(x, y, z)\}S_{\nu}(y', z')
\]

In this instance, the set \( M_{2,t}(x, y, z) \) is simple to define:

\[
M_{2,t}(\phi_{0,t}(x, y, z), x, y, z) \equiv \{y', z'|S_t(x, y, z) > S_t(x, y', z') > \beta S_t(x, y, z)\}
\]

Our wage equation simplifies further to:

\[
\phi_{0,t}(x, y, z) = f_t(x, y, z) - (1 - \beta)(r + \delta_t + \eta_t)S_t(x, y, z) \\
- (1 - \beta)\lambda_{1,t}S_t(x, y, z)\int \int_{y', z' \in M_{1,t}(x, y, z)} v(y')\gamma(z')dy'dz' \\
- \lambda_{1,t}\int \int_{y', z' \in M_{2,t}(x, y, z)} [S_t(x, y', z') - \beta S_t(x, y, z)]v(y')\gamma(z')dy'dz' \\
+ \eta_t(1 - \beta)1\{\theta_t \notin N_{0,\nu}(x, y, z)\}S_{\nu}(y', z')
\]

**A.4 Wages with Outside Options**

We substitute \( \phi_{1,t}(x, y, z, y', z') \) into the option value of employment presented earlier. To review, \( \phi_{1,t}(x, y, z, y', z') \) represents the wage a worker of type \( x \) in period \( t \) working for a firm of type \( y \)
with match draw to earn if his best outside offer is the pair \((y', z'):\)

\[
(r + \delta_t + \eta_t) (W_t (\phi_1, (x, y, z, y', z'), y, z) - U_t (x)) = \phi_1 (x, y, z, y', z') - b_t (x)
\]

\[
+ \lambda_1 \int \int_{y', z'' \in M_{11, t}(x, y, z)} [W_t (\phi_1(x, y'', z''), x, y'', z'')] - W_t (\phi_1(x, y, z, y', z'), x, y, z)] v(y'') \gamma(z'') d\gamma dz''
\]

\[
+ \lambda_1 \int \int_{y', z'' \in M_{11, t}(x, y, z)} [W_t (\phi_1(x, y'', y, z), x, y'', z'')] - W_t (\phi_1(x, y, z, y', z'), x, y, z)] v(y'') \gamma(z'') d\gamma dz''
\]

\[
+ \lambda_1 \int \int_{y', z'' \in M_2 (x, y, z, y', z')} [W_t (\phi_1(x, y', z''), x, y, z)] v(y'') \gamma(z'') d\gamma dz''
\]

\[
- W_t (\phi_1(x, y, z, y', z'), y, z)] v(y'') \gamma(z'') d\gamma dz'' - \beta \lambda_0 \int \int_{y', z'' \in M_{0, t}(x)} S_t (x, y'', z'') v(y'') \gamma(z'') d\gamma dz''
\]

\[
+ \eta_t \left[1{\theta' \in N_1} \{v' \in N_1} (x, y, z, y', z')] \{W_t (\phi_1, (x, y, z, y', z'), x, y, z) - U_t (x))
\]

\[
+ 1{\theta' \in N_2} (x, y, z, y', z')] \{W_t (\phi_0, (x, y, z, y', z'), x, y, z) - U_t (x))
\]

\[
+ 1{\theta' \in N_3} (x, y, z, y', z')] \{W_t (\phi_1, (x, y, z, y', z'), x, y, z) - U_t (x))
\]

Applying the same wage identity identities, we get:

\[
(r + \delta_t + \eta_t) S_t (x, y', z') = \phi_1 (x, y, z, y', z') - b_t (x)
\]

\[
+ \lambda_1 \int \int_{y', z'' \in M_{0, t}(x, y, z)} [\beta S_t (x, y'', z'') - S_t (x, y', z')] v(y'') \gamma(z'') d\gamma dz''
\]

\[
+ \lambda_1 \int \int_{y', z'' \in M_{11, t}(x, y, z)} [S_t (x, y, z) - S_t (x, y', z')] v(y'') \gamma(z'') d\gamma dz''
\]

\[
+ \lambda_1 \int \int_{y', z'' \in M_{2, t}(x, y, z, y', z')} [S_t (x, y'', z'') - S_t (x, y', z')] v(y'') \gamma(z'') d\gamma dz''
\]

\[
- \beta \lambda_0 \int \int_{y', z'' \in M_{0, t}(x)} S_t (x, y'', z'') v(y'') \gamma(z'') d\gamma dz''
\]

\[
+ \eta_t \left[1{\theta' \in N_1} \{v' \in N_1} (x, y, z, y', z')] S_t (x, y', z') + 1{\theta' \in N_2} (x, y, z, y', z')] \beta S_t (x, y, z)
\]

\[
+ 1{\theta' \in N_3} (x, y, z, y', z')] S_t (x, y, z)
\]

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Substituting in the value of $S_t(x, y', z')$ from equation (4) gives:

$$\phi_{1,t}(x, y, z, y', z') = f_t(x, y', z') \quad - \lambda_{1,t} \int \int y', z' \in M_{11, t}(x, y, z) [S_t(x, y, z) - S_t(x, y', z')] v(y') \gamma(z') dy' dz'$$

$$- \lambda_1 \int \int y', z' \in M_{2, t}(\phi_1(x, y, z, y', z'), x, y, z) [S(x, y', z') - S(x, y', z')] v(y') \gamma(z') dy' dz'$$

$$+ \eta_1 \{ \theta \in N_{2, t} (x, y, z, y', z') \} [S_{t'} (x, y', z') - \beta S_{t'} (x, y, z)]$$

$$+ \eta_1 \{ \theta \in N_{3, t} (x, y, z, y', z') \} [S_{t'} (x, y', z') - S_{t'} (x, y, z)]$$

As only a worker’s last job is important, the set $M_2(\cdot)$ can be defined without the wage:

$$M_{2, t}(x, y, z, y', z') = \{ y', z' \mid S(x, y, z) > S(x, y', z') > W(\phi_1(x, y, z, y', z'), y, z) - U(x) \}$$

$$M_{2, t}(x, y', z') = \{ y', z' \mid S(x, y, z) > S(x, y', z') > S(x, y', z') \}$$

$$\phi_{1,t}(x, y, z, y', z') = f_t(x, y', z') \quad - \lambda_{1,t} \int \int y', z' \in M_{11, t}(x, y, z) [S_t(x, y, z) - S_t(x, y', z')] v(y') \gamma(z') dy' dz'$$

$$- \lambda_1 \int \int y', z' \in M_{2, t}(x, y, z) [S(x, y', z') - S(x, y', z')] v(y') \gamma(z') dy' dz'$$

$$+ \eta_1 \{ \theta \in N_{2, t} (x, y, z, y', z') \} [S_{t'} (x, y', z') - \beta S_{t'} (x, y, z)]$$

$$+ \eta_1 \{ \theta \in N_{3, t} (x, y, z, y', z') \} [S_{t'} (x, y', z') - S_{t'} (x, y, z)]$$

**A.5 Proof of Proposition 3**

To verify that the set $M_{2, t}(w, x, y, z)$, as defined in the main body of the text, is non-empty for some $(t, w, x, y, z)$, we provide an example. Assume $t$ is such that $\mu_t = 0$, which in the context of our application is either at the pre-announcement of the policy or after full implementation.

Further, assume $w = \phi_{1,t}(x, y, z, y, z)$. This wage rate could arise because of a re-negotiation after the implementation of a policy or because of competing job offers of identical value. Inspection of equation (4) coupled with the matching set $M_{2, t}(x, y, z)$ defined above reveals that under these assumptions a worker receives a wage equal to his marginal product, $w = f_t(x, y, z)$. 

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Then for any firm and match draw \((y', z')\) such that the offer is strictly preferred, \(S_t(x, y', z') > S_t(x, y, z)\), the new wage offer is:

\[
\phi_{1,t}(x, y', z', y, z) = f_t(x, y, z)
\]

\[
- \lambda_{1,t} \int \int_{y'', z'' \in M_{11,t}(x,y,z)} [S_t(x, y', z') - S_t(x, y, z)] v(y'') \gamma(z'') dy'' dz''
\]

\[
- \lambda_{1,t} \int \int_{y'', z'' \in M_{12,t}(\phi_t(x, y', z', y, z), x, y, z)} [S(x, y'', z'') - S(x, y, z)] v(y'') \gamma(z'') dy'' dz'' < w
\]

Q.E.D.

A.6 Solving the ODE Defining Labor Market Dynamics

The ordinary differential equation (ODE) defining unemployment for \(t \in \tau_i\) is written in standard form:

\[
\dot{u}_t(x) + \left( \delta_t + \lambda_{0,t} \int \int_{y,z \in M_{0,t}(x)} v(y') \gamma(z') dy dz \right) u_t(x) = \delta_t \ell(x)
\]

Multiplying by the integrating factor gives:

\[
\frac{d}{dt} \left\{ u_t(x) \exp \left( \left( \delta_t + \lambda_{0,t} \int \int_{y,z \in M_{0,t}(x)} v(y') \gamma(z') dy dz \right) (t - t_i) \right) \right\} = \delta_t \ell(x) \exp \left( \left( \delta_t + \lambda_{0,t} \int \int_{y,z \in M_{0,t}(x)} v(y') \gamma(z') dy dz \right) (t - t_i) \right)
\]

Integrating both sides with respect to \(t\) yields the particular solution given below, where \(C(x)\) is the constant of integration:

\[
u_t(x) = \frac{\delta_t \ell(x)}{\delta_t + \lambda_{0,t} \int \int_{y,z \in M_{0,t}(x)} v(y') \gamma(z') dy dz} \exp \left( \left( \delta_t + \lambda_{0,t} \int \int_{y,z \in M_{0,t}(x)} v(y') \gamma(z') dy dz \right) (t - t_i) \right) + \frac{C(x)}{\delta_t + \lambda_{0,t} \int \int_{y,z \in M_{0,t}(x)} v(y') \gamma(z') dy dz} \exp \left( \left( \delta_t + \lambda_{0,t} \int \int_{y,z \in M_{0,t}(x)} v(y') \gamma(z') dy dz \right) (t - t_i) \right)
\]

Substituting in the initial condition when \(t = t_i\) and unemployment is equal to \(u_{t_i}\) which is known and given by equation [10], the constant of integration can be solved, where \(u_{ss,t}\) is the contemporaneous steady-state unemployment rate and the solution to equation [8].

\[
C(x) = u_{t_i}(x) - u_{ss,t}(x)
\]
By substituting back into the particular solution one gets the more convenient ODE defining the unemployment rate.

\[ u_t(x) = u_{ss,t}(x) \left( 1 - \exp \left( \left( \delta_t + \lambda_{0,t} \int_{y,z \in M_0(x)} v(y')\gamma(z')dydz \right) (t_i - t) \right) \right) 
+ u_{t_i}(x) \exp \left( \left( \delta_t + \lambda_{0,t} \int_{y,z \in M_0(x)} v(y')\gamma(z')dydz \right) (t_i - t) \right) \]

A.7 Data Series

Figure A1: Wage moments of new hires and correlations 2001-2005

**Note:** Log real re-entry wages refer to the natural log of daily wages in Euros for new hires, which are deflated by the Consumer Price Index. The monthly series are based on SIAB data and are seasonally adjusted using the X-12-Arima program.
Figure A2: Transition rates and unemployment duration 2001-2005

**Note:** The monthly series are based on SIAB data and are seasonally adjusted using the X-12-Arima program. Firms are ranked based on their average 75th-percentile real wage for full-time employees during the period January 2001 to December 2005.
A.8 Forecasts

Figure A3: Forecast for low-skill workers

Note: All transition rates are monthly. The black dotted line represents the data, the blue points are those that the forecast inference is based upon, the solid black line is the forecast and the heat map represents a 95% confidence interval.
Figure A4: Forecast for medium-skill workers

Note: All transition rates are monthly. The black dotted line represents the data, the blue points are those that the forecast inference is based upon, the solid black line is the forecast and the heat map represents a 95% confidence interval.
Figure A5: Forecast for high-skill workers

**Note:** All transition rates are monthly. The black dotted line represents the data, the blue points are those that the forecast inference is based upon, the solid black line is the forecast and the heat map represents a 95% confidence interval.

### A.9 The Fit of the Model
Figure A6: Simulated series for the low-skilled

Note: The solid black line represents the data and the blue line the simulations, 95% confidence intervals are represented by the shaded area and obtained by repeated re-simulations.
Figure A7: Simulated series for the medium-skilled

Note: The solid black line represents the data and the blue line the simulations, 95% confidence intervals are represented by the shaded area and obtained by repeated re-simulations.
Figure A8: Simulated series for the high-skilled

Note: The solid black line represents the data and the blue line the simulations, 95% confidence intervals are represented by the shaded area and obtained by repeated re-simulations.
A.10 Steady-State Revisited

Further to Section 3.7.1, the pool of employed agents are divided into two types. The first type are the employed who have not received credible outside offers, and whose threat point in wage bargaining is therefore unemployment. A second type are the employed who have received credible offers while in employment and have therefore managed to re-negotiate their wage using employment in another firm as leverage in the bargaining process. The measure of the first employment type only varies with $x, y$ and $z$, the productivity triple of the current match. The second measure, however, varies with $x, y$ and $z$ and similarly with $y'$ and $z'$, the second best offer the worker has received since he left unemployment. We also impose stability on these two measures and call them $e_0(x, y, z)$ and $e_1(x, y, z, y', z')$, respectively.

Firstly, we equalize the flow in and out of $e_0(x, y, z)$ for all $x, y$ and $z$. Workers exit to unemployment $u(x)$ if they exogenously lose their job, with probability $\delta$. They can also exit to employment with a higher outside option. Exit is either to a different firm, using the current employer as leverage (if $y', z' \in M_1(x, y, z)$ ) or they stay with the same employer, using the firm attempting to poach for leverage (if $y', z' \in M_2(\phi_0(x, y, z), x, y, z) )$.

$$e_0(x, y, z) \left[ \delta + \lambda_1 \int \int_{y', z' \in \{ M_1(x, y, z) \cup M_2(\phi_0(x, y, z), x, y, z) \}} v(y') \gamma(z') dy' dz' \right] = \lambda_0 u(x) v(y) \gamma(z) 1\{ y, z \in M_0(x) \}$$

This expression can be computed directly, by defining the set $y', z' \in \{ M_1(x, y, z) \cup M_2(\phi_0(x, y, z), x, y, z) \}$, and using the fact that $\beta \in (0, 1)$ as well as the identity given by equation (2).

$$\{ M_1(x, y, z) \cup M_2(\phi_0(x, y, z), x, y, z) \} = \{ y', z' | S(x, y', z') > S(x, y, z) \}$$
$$\cup \quad S(x, y, z) > S(x, y', z') > \beta S(x, y, z) \}$$
$$= \{ y', z' | S(x, y', z') > \beta S(x, y, z) \}$$

Thus, the steady-state measure $e_0(x, y, z)$ can be directly computed. To solve for $e_1(x, y, z, y', z')$ one needs to implement an iterative solution. The steady-state condition defining $e_1(x, y, z, y', z')$, for which indicator functions are used rather than matching sets, is given by:

$$\{ M_1(x, y, z) \cup M_2(\phi_0(x, y, z), x, y, z) \} = \{ y', z' | S(x, y', z') > S(x, y, z) \}$$
$$\cup \quad S(x, y, z) > S(x, y', z') > \beta S(x, y, z) \}$$
$$= \{ y', z' | S(x, y', z') > \beta S(x, y, z) \}$$
\[ e_1(x, y, z, y', z') \left[ \delta + \lambda_1 \int \int 1\{S(x, y'', z'') > S(x, y', z')\} v(y'') \gamma(z'') dy'' dz'' \right] \]
\[ = \lambda_1 v(y) \gamma(z) 1\{S(x, y, z) > S(x, y', z')\} e(x, y', z') \]
\[ + \lambda_1 e_0(x, y, z) v(y') \gamma(z') 1\{S(x, y, z) > S(x, y', z') > \beta S(x, y, z)\} \]
\[ + \lambda_1 v(y') \gamma(z') \int \int 1\{S(x, y, z) > S(x, y', z') > S(x, y'', z'')\} e(x, y, z, y'', z'') dy'' dz'' \]

### A.11 Wage Projection

The data are simulated such that for an individual \( i \) we have his wage \( w_i \), his unobserved type \( x_i \), the type of his employer \( y_i \), his match specific quality \( z_i \), if applicable his best outside offer that includes firm and match components \( y'_i \) and \( z'_i \), and the strata he belongs to, which equals \( k = 1 \) for low-skilled, \( k = 2 \) for medium-skilled and \( k = 3 \) for high-skilled workers. We then estimate the below relationship, where \( \{k = n\} \) is a dummy variable taking the value one if the skill group is type \( n \) and zero otherwise. Since our production function accounts for circle sorting, we follow [Gautier and Teulings (2006)] and include a square term for each parameter. This improves the fit compared to a linear specification with an \( R^2 \)-value of approximately 0.8 to 0.9 in both pre- and post-reform projections. Higher order polynomials add little explanatory power and including them does not change the results significantly.

\[
\log w_i = \rho_0 + \sigma_1 x_i + \sigma_2 x_i^2 + \tau_1 y_i + \tau_2 y_i^2 + v_1 z_i + v_2 z_i^2 \\
+ \phi_1 y'_i + \phi_2 y'_i^2 + \chi_1 z'_i + \chi_2 z'_i^2 + \psi_1 \{k = 1\} + \psi_2 \{k = 2\} + \epsilon_i
\]

After carrying out this regression we project wages on to \((\tilde{x}_i, \tilde{y}_i, \tilde{z}_i, \tilde{f})\) by means of ordinary least squares, where the vector is defined as below and estimates are denoted by hats.

\[
\tilde{x}_i = \hat{\sigma}_1 x_i + \hat{\sigma}_2 x_i^2 + \hat{\psi}_1 \{k = 1\} + \hat{\psi}_2 \{k = 2\} \\
\tilde{y}_i = \hat{\tau}_1 y_i + \hat{\tau}_2 y_i^2 \\
\tilde{z}_i = \hat{v}_1 z_i + \hat{v}_2 z_i^2 \\
\tilde{f}_i = \hat{\phi}_1 y'_i + \hat{\phi}_2 y'_i^2 + \hat{\chi}_1 z'_i + \hat{\chi}_2 z'_i^2
\]
Differences in strata are assigned to worker differences, which may underreport firm, match and frictional variation. For example, systematic differences in firm quality might arise depending on which skill group firms hire from.