Employment and Welfare Effects of Short-Time Work

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March 2017

Abstract

We study the employment and welfare effects of short-time work — a government program that subsidizes part-time work during economic downturns — in Germany between 2008 and 2010. Using administrative data, we document that take-up of short-time work is increasing in experience and tenure, almost all short-time workers eventually return to full-time work, and — in contrast to unemployment — short-time work is not associated with a long-term loss in earnings. We develop a theory of short-time work that is consistent with these facts. Our model features search frictions, aggregate and idiosyncratic shocks, and general- and firm-specific human capital. Productivity shocks differ in duration and magnitude, and when hit by an adverse temporary productivity shock, firms can curtail their losses by reducing working hours. Firms' ability to adjust working hours is limited, because workers may quit. The main determinants of short-time work take-up are worker's human capital and the duration of productivity shocks. Using our estimated model, we find that short-time work substantially reduced job loss in the recession. The welfare gains are modest, because workers who would have been laid off without short-time work are workers for whom the earnings loss associated with unemployment is low.

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This paper uses various administrative data sources from the Institute for Employment Research (IAB) and the German Federal Employment Agency. We thank everyone who was involved in collecting individual-level short-time worker data and permitting us to use them. We thank Hanming Fang, Guido Menzio, and Andrew Shephard for guidance. We are grateful to Sushant Acharya, Björn Brügemann, Keshav Dogra, Chris Flinn, Qing Gong, Nick Janetos, Gregor Jarosch, Fatih Karahan, Ami Ko, Rossa O'Keeffe-O'Donovan, Vivian Leemans, Laura Pilossoph, Aysegul Sahin, Kris Shaw, Petra Todd, and seminar participants at Penn, the New York Fed, IZA/CREST/Bonn University Workshop, the Philadelphia Search and Matching Workshop, the Econometric Society North American Summer Meeting in Philadelphia, and the ZEW Summer Workshop for helpful comments and suggestions.

1 Introduction

During the recession between 2008 and 2010, a large fraction of Germany's labor force took up short-time work, reaching as much as 6.5% in 2009.[1] Short-time work is a government program that subsidizes part-time work in recessions. When employers cut their workers' hours and — in proportion — earnings, the government partially compensates workers for this reduction in earnings. Short-time work is based on the premise that during recessions, some productivity declines are temporary. It provides financial incentives to prevent workers from being laid off in response to such temporary declines. In this paper, we study Germany's experience with short-time work.[2] Using worker-level administrative data, we document which workers take up short-time work and then develop and structurally estimate an equilibrium search model to determine the effects of short-time work on employment and welfare.

We assemble a new administrative dataset of the universe of workers in the metropolitan area of Nuremberg that includes detailed information on short-time work.[3] We document three facts. First, short-time work take-up is increasing in experience and tenure. Second, almost all short-time workers return to full-time work when their short-time work spell ends. Third, short-time workers do not experience long-term effects on earnings or employment. In contrast, we document that laid off workers experience a long-term loss in earnings and that this loss is largest for workers who are experienced and have high tenure at the time of the layoff.[4]

We develop and structurally estimate an equilibrium life-cycle model that is consistent with these facts. The model features search frictions, aggregate and match-specific shocks, general- and firm-specific human capital, and an intensive margin. Using our estimated model, we find that short-time work substantially reduced job loss during the recession. The welfare gains are modest, because workers who would have been laid off without short-time work are workers for whom the earnings loss associated with unemployment is low.

Worker-firm matches are hit by productivity shocks that differ in magnitude and duration. During recessions, productivity shocks tend to be worse in magnitude but shorter in duration

[1]We report the share of short-time workers relative to the *attached* labor force, i.e. individuals who are currently or were recently employed in full-time jobs subject to social security contributions. As a point of reference, there were 1.4 million short-time workers and 3.6 million unemployed workers in Germany in April 2009.

[2]Germany is not the only country with widespread take-up of short-time work during the recession following the financial crisis in 2008. See Cahuc and Carcillo (2011) and Hijzen and Venn (2011) for an overview of short-time take-up during that time across OECD countries, Messenger and Ghosheh (2013) for case studies of Austria, Belgium, France, Germany, Japan, the Netherlands, Turkey, and Uruguay, and Aricò and Stein (2012) for a comparison between short-time work schemes in Germany and Italy. Even though 17 U.S. states were operating short-time work schemes during the recession, take-up was very small (Abraham and Houseman, 2014).

[3]In the usual administrative datasets for Germany, short-time workers cannot be identified, because they appear as if they are working their regular working hours. We are not the first to notice this. Scholz (2012) uses a precursor of the data used in this paper. Other papers rely on firm-level data, e.g. Boeri and Bruecker (2011), Kruppe and Scholz (2014), Balleer et al. (2016), Cooper et al. (2016).

[4]These findings are in line with the extensive literature on the effects of worker displacement on future employment and earnings, e.g. Jacobson et al. (1993), Davis and von Wachter (2011).

than in normal times. Each period, workers and firms observe the magnitude and expected duration of their current productivity shock. Firms then decide whether to keep the worker employed and for how many hours. Workers decide whether to stay employed or quit. Ordinarily, the firm's ability to reduce working hours is limited, because the worker can quit, in which case she receives unemployment insurance benefits and searches for a different job. With short-time work, working reduced hours becomes more attractive to workers.

Workers with substantial firm-specific human capital are unlikely to quit or be fired in response to a temporary shock. This explains why short-time take-up is increasing in tenure and why these workers experience severe earning losses when they do lose their jobs (e.g. due to a persistent adverse match productivity shock). Workers with little firm-specific human capital have little to lose from unemployment. When hit by an adverse temporary productivity shock, these workers separate from their employer instead of waiting for their current match productivity to improve. For these workers, the earnings loss associated with unemployment is small.

Since we study how firms and workers respond to temporary productivity shocks, we explicitly allow for temporary unemployment as in Fujita and Moscarini (2016) and Fernández-Blanco (2013). When a firm lays a worker off, the firm can subsequently recall the unemployed worker and resume the employment relationship if the worker did not find a different job and the worker and the firm did not lose contact for other reasons. This feature of the model — which is supported by the data in which about 11% of all unemployed workers return to their previous employer — implies that short-time work is not the only way for workers and firms to respond to temporary downturns. In our model, there are important differences between short-time work and a temporary layoff. First, short-time workers do not lose human capital, whereas unemployed workers do. Second, short-time workers are less likely to search and find alternative jobs than unemployed workers (if not only because the latter have more time to search). Third, short-time workers do not lose contact with their employer for exogenous reasons, whereas recall of temporarily unemployed workers is uncertain.

We assume that the hourly wages of incumbent workers cannot flexibly respond to temporary productivity shocks. We deem this a realistic restriction on the contract space for the German labor market, where many employment relationships are governed by collective bargaining agreements.[5] This restriction ensures that in the model — as in the data — the main response to the recession is in hours worked, not in the hourly wage.[6]

[5]Note that some of these arrangements are more flexible than implied by our assumption. See for instance Dustmann et al. (2014).

[6]This fact is otherwise difficult to square with more flexible contractual arrangements. When hours and wages can flexibly respond to productivity shocks, a change in working hours should also coincide with a change in the hourly wage. Note that other than contractual obligations, there are many institutional features in the German labor market that make wages rigid, e.g. the fact that the level of wages have immediate consequences for future generosity of unemployment insurance benefits and pension benefits. We do not seek to provide micro foundations

Even though the model features aggregate dynamics and rich worker-level heterogeneity, and search on- and off-the-job, it is tractable, because search is directed as in Menzio and Shi (2011). Our model admits a unique recursive equilibrium and this equilibrium is block recursive, i.e. it can be computed independently of the distribution of workers across states.[7]

We estimate the model using indirect inference. According to our estimated model, short-time work was responsible for decreasing the unemployment rate by 1.3 percentage points in 2009, i.e. about one in five short-time workers (short-time take-up equalled 6% in 2009) would have been unemployed. The welfare benefits of the policy are modest. Measured in consumption equivalents, the average worker values the policy at about 1.0% of her annual income in 2009. The combined cost to the government and firms totals about 0.7% of the average worker's annual income.

We use the estimated model to study what combination of unemployment insurance benefits and short-time compensation (i.e. benefits paid to workers who take up short-time work, which is proportional to their reduction in earnings) maximizes the average worker's welfare. We take into account that the government needs to adjust payroll taxes to balance its budget. We find that the optimal replacement rate of unemployment insurance equals 55%. The optimal replacement rate of short-time compensation is close to 100%. Thus, the optimal replacement rate for the unemployed is just a little bit lower than the actual replacement rate that equals 60% (or 67% if the recipient has children). The optimal replacement rate for short-time workers is considerably higher than the actual replacement rate, which is the same as for the unemployed.

We estimate our model from observational data alone. However, since our ultimate goal is to assess the employment and welfare implications of a particular labor market policy, we corroborate the findings from our structural model by estimating the immediate effect of short-time work on job destruction rates.[8] We exploit the fact that Germany's short-time work program was expanded in January 2009, at which point the policy became more generous, less restrictive, and easier to use. We compare job destruction rates between industries that were adversely affected by the recession before short-time work was expanded and industries that experienced the recession afterwards. Our direct estimates are in line with the model implied effect of short-time work on job destruction rates.

Our view on short-time work in this paper is purposefully narrow. We exclusively focus on the dynamic implications that temporary shocks may have on workers' careers and how short-

for the origin of wage rigidity. Also, we ignore that in reality, some short-time work arrangements coincide with temporary wage reductions (called *Lohnverzicht* in German) since we find that this only applies to a relatively small number of short-time workers.

[7]See also Guo (2015) and Menzio et al. (2016) for papers that incorporate directed search in life-cycle models.

[8]Studying short-time work in Germany provides a formidable identification challenge, because there is no obvious counterfactual. Short-time work is a federal policy (as opposed to state-wide) that is only available during recessions. Therefore, we cannot use time-variation to study the effects of short-time work on employment, because by construction the availability of short-time work is correlated with the aggregate state of the economy. We also cannot use geographic variation, because the policy is available nationwide.

time work interacts with human capital. Our detailed treatment of worker-level heterogeneity comes at a cost. We treat all productive activity as resulting from single-worker firms. We ignore interaction effects between workers at the same firm and how firms allocate work between workers. As a result, our paper has a different focus than much of the existing literature on short-time work (e.g., Burdett and Wright (1989), Van Audenrode (1994), Braun and Brügemann (2017), Cooper et al. (2016)). However, the existing literature largely considers models with homogeneous workers.

Our approach to modeling the effect of short-time work on workers' careers is related to the extensive literature on the effects of job loss on the evolution of employment and earnings. Our model shares features with Huckfeldt (2016), Jung and Kuhn (2016), and Jarosch (2016) who study how job loss results in long-term earning losses. These papers have in common that layoffs interact with human capital and thereby result in persistent earning losses. However, these papers also have in common that the main reason for layoffs is exogenous. Our model differs from these papers along various dimensions. Most importantly, in our model, the layoff of a worker is a choice — not an exogenous event that is outside of the firm's or the worker's control. In particular, workers can prevent being laid off by tolerating a temporary reduction in hours. The role of short-time work is to make this reduction in hours and earnings more attractive to workers. That in turn implies that if layoffs have severe negative consequences for the worker, then the worker will do everything in her power to prevent being laid off. This bounds the potential benefits from a government policy such as short-time work.

Three papers have studied short-time work using equilibrium search models. Cooper et al. (2016) and Balleer et al. (2016) study the take-up of short-time work in Germany between 2008 and 2010, and Osuna and García-Pérez (2015) study the counterfactual introduction of short-time work in Spain while emphasizing the distinction between long-term and temporary employment contracts. Neither of these papers explicitly models human capital.

Most of the theoretical research on short-time work has focused on how firms allocate work between different workers abstracting from search frictions, aggregate shocks, and human capital. Burdett and Wright (1989) study the welfare and employment effects of regular unemployment insurance vis-à-vis short-time work. They find that an environment that features only regular unemployment insurance induces inefficient layoffs. In contrast, an environment with short-time work does not, but it leads to inefficiently chosen working hours. Van Audenrode (1994) and Braun and Brügemann (2017) build on the work by Burdett and Wright (1989). Van Audenrode finds that short-time compensation must be proportionally more generous than traditional unemployment insurance systems to induce workers into accepting variable hours. If short-time compensation is too low, it may result in both inefficient employment and inefficient choice of hours. Braun and Brügemann include a distinction between insurable and uninsurable risk. There are some shocks, for which the firm will stop producing and will lay off all workers. Against all other shocks, the firm can obtain perfect insurance. When firms can insure well, then short-time work can be welfare improving by reducing inefficient layoffs that are caused by the unemployment insurance system. If firms are poorly insured, then short-time work cannot improve welfare.

Previous empirical studies on short-time work in Germany usually find little to no effect of short-time work on employment. Most of these studies either rely on cross-country comparisons (e.g. Cahuc and Carcillo (2011) and Hijzen and Venn (2011)) or firm-level data with relatively coarse measurements of short-time take-up (e.g. Boeri and Bruecker (2011), Bellmann and Gerner (2011), Crimmann et al. (2010)). Two papers on short-time work in Germany, Scholz (2012) and Kruppe and Scholz (2014), use detailed worker-level and firm-level data, respectively. Scholz (2012) uses a precursor of our dataset and investigates whether short-time workers differ from full-time workers based on characteristics such as education and seniority and finds no such differences. Kruppe and Scholz (2014) investigate whether firms with short-time work exhibit different employment behavior than firms without short-time work and also find no such differences.

This paper is structured as follows. In Section 2, we provide background on the German short-time work scheme. In Section 3, we introduce our dataset and develop several stylized facts on short-time work. In Section 4, we introduce our model. Section 5 discusses how to estimate the model. Section 6 presents the effects on employment and welfare. In Section 7, we study the optimal policy design of short-time compensation and unemployment insurance benefits. In Section 8, we corroborate the results from our estimated model with more direct empirical evidence. Section 9 concludes.

2 Background

Germany's current system of short-time work was introduced in 1957.[9] There are several types of short-time work. Throughout we will focus on what is called "short-time work for economic reasons," the most prominent type of short-time work. Other types include seasonal short-time work for workers in industries that are adversely affected by weather conditions and restructuring short-time work for workers in firms that undergo restructuring. Before the recession between 2008 and 2010, there were several episodes of extensive short-time use. These episodes include the second half of the 1960s, during the oil crisis in the 1970s, and the early 1980s.[10] In the two economic downturns in the years 1996–1997 and 2001–2004, there was no large scale use of short-time work. Between 2008 and 2010, several policy changes made short-time work more attractive to firms and workers, which we outline below.

Short-time work makes it easier for employers to reduce their workers' hours during downturns. When an employer reduces a worker's working hours and — in proportion — earnings,

[9]Precursors of the current system date back to the early 20th century.
[10]In the years after the reunification, there was large-scale take-up of restructuring short-time work.

the worker receives short-time compensation from the Federal Employment Agency on the foregone earnings. Short-time compensation is equal to the unemployment insurance benefits the worker would have received if unemployed pro-rated by the reduction in working hours. Essentially, short-time work can be thought of as hourly unemployment insurance. The replacement rate equals 60% for workers without children and 67% for workers with children. Unemployment insurance benefits and short-time compensation are assessed on the worker's after tax salary. Both types of government transfers are not subject to income taxes.

We refer to a worker's full-time salary before a short-time spell as "regular earnings" and to a worker's wage earnings during short-time work as "prorated earnings." A short-time worker's total compensation is the sum of prorated earnings and short-time compensation. We refer to the difference in regular earnings and prorated earnings as "foregone earnings."

Short-time work also has implications for employers' social security contributions. In Germany, social security contributions are split between the worker and the firm. The worker's share of the social security tax is approximately equal to the firm's share. A short-time worker's social security contributions are paid in full on the worker's regular earnings. However, the worker is only responsible for her share of social security contributions on the prorated earnings. The employer is responsible for the entire remainder, i.e. the firm's share of social security contributions on the regular earnings as well as the worker's share of social security contributions on the foregone earnings. Because of this, a firm's cost of employing a worker is not linear in hours. The more a firm reduces a worker's hours, the higher the per-hour cost of employing the worker. These tax implications of short-time work are non-negligible, because in Germany, the social security tax can amount to as much as 40% of a worker's regular earnings. The social security tax is so high, because it includes, among others, contributions to the public pension system, health insurance, long-term care insurance, and unemployment insurance system.

There are several preconditions for a worker to receive short-time compensation. First, the worker and the firm need to jointly agree on the reduction in hours. In smaller firms, employers and workers negotiate short-time work on a case-by-case basis. In larger firms, where workers' interests are represented by a workers' council or some form of union representation, these representatives of the workers need to agree to the reduction in working hours. Second, employers have to seek approval for short-time work from the Federal Employment Agency. Approval requires that employers demonstrate that they face temporary and unavoidable financial difficulties that necessitate layoffs. Citing the adverse consequences of a recession is usually satisfactory to obtain approval. Once an employer's request for short-time work is approved, the employer can freely make use of short-time work and does not need to get separate approvals for additional short-time workers or additional months of short-time work. Third, other means of reducing working hours must have been depleted. In particular, if a worker has accrued overtime in a working-time account, the worker must first take compensatory time off, before she can receive short-time compensation.

Employers have to report each worker's reduction in hours to the Federal Employment Agency on a monthly basis. The agency then pays the total amount of short-time compensation to the firm, which disburses the funds among its employees. These monthly reports will serve as our data source as we outline in Section 3.

Beginning in January 2009, several rules that govern short-time work were changed. All policy changes aimed to make short-time work more attractive. We highlight three major policy changes.[11] First, in January 2009, the maximum duration for which a worker may receive short-time compensation was increased from 12 months to 18 months. In July 2009, the duration was further extended to 24 months. Second, in February 2009, the social security tax burden on firms was reduced. Instead of being responsible for the entire remainder of social security contributions, firms were now only responsible for half of the social security contributions on their workers' foregone earnings. In July 2009, these rules were further relaxed. For all short-time spells exceeding six months, the government covers the entire share of social security contributions on workers' foregone earnings. Third, in February 2009, one additional restriction on short-time work was removed. Ordinarily, firms can only apply for short-time work if they reduce the number of working hours by an average of at least 10% for at least 30% of their workforce. This equal treatment provision is meant to make short-time work more equitable and share the burden across the workforce. In February 2009, this rule was removed. Firms were now able to apply for short-time work on an individual worker-level basis as long as the reduction in hours exceeded 10%. All in all, these statutory changes that occurred in January and February 2009 made short-time work more attractive for employers.[12]

Besides the various statutory changes, there were also changes in the approval process. Throughout the 2008–2010 recession, the Federal Employment Agency approved almost all requests for short-time work. In 2009, only 0.45% of short-time work requests were denied. In addition, there was substantial political will to expand the short-time work program and funding was allocated accordingly.

Short-time work does not exist in a vacuum. There are several other institutions and policies that govern the German labor market and affect how flexibly workers and firms can respond to downturns. These institutions include collective bargaining and firm-level agreements. Policies include firing restrictions and different contracting regimes (permanent vs. temporary positions). Some of these institutions and policies are discussed in Burda and Hunt (2011) and Dustmann et al. (2014).

[11] Table 1 shows the entire list of policy changes.

[12] There were additional policy changes that we do not discuss in detail. For instance, the government covers 100% of social security contributions on foregone earnings for workers who received training during the reduced working hours. Also, short-time work was made available to temporary workers.

Date	Duration	Eligibility	Cost
Before December 2006	6 months	Reduce hours of at least 33% of staff by at least 10% ("33/10 rule")	Firms pay all social security contributions.
January 2007	15 months	33/10 rule	Firms pay all social security contributions.
July 2007	12 months	33/10 rule	Firms pay all social security contributions.
January 2009	18 months	33/10 rule	Firms pay all social security contributions.
February 2009	18 months	Reduce hours of at least one employee by at least 10%. Firms that satisfy the 33/10 rule can make use of short-time work provisions for all workers for any reduction in hours. Firms that do not satisfy the 33/10 provision can make use of short-time work only for workers with a 10% reduction in hours.	Firms pay 50% of social security contributions
July 2009	24 months	As above.	As above. As of the seventh month, the Federal Employment Agency pays 100% of social security contributions
January 2010	18 months	As above.	As above.
January 2011	12 months	As above.	As above.
January 2012	6 months	33/10 rule	Firms pay all social security contributions.
January 2013	12 months	33/10 rule	Firms pay all social security contributions.

Table 1: Timeline of Policy Changes 2006–2013

Note: The table contains a list of the main policy changes to short-time work before, during, and after the recession. The main changes include an extension of benefit duration, a switch to an individual-worker- based system, and payroll tax relief for firms.

3 Data

3.1 Data Sources

The *Institute for Employment Research* (IAB), the research unit of Germany's Federal Employment Agency, makes detailed administrative labor market data available to researchers. However, studying short-time work in Germany is difficult, because the usual administrative data sources do not contain any information on short-time work. German administrative data sources solely collect data that are relevant for social security purposes. Short-time work has no impact on worker's social security contributions as a short-time worker's social security contributions are paid in full on the worker's regular earnings.[13] Therefore, short-time workers appear in the data based on their regular employment status (full-time or part-time) and their regular earnings. We overcome this difficulty by assembling a new dataset based on three different data sources that we describe below.

The first data source consists of the short-time work take-up decisions for the universe of short-time workers in the Nuremberg metropolitan area. Employers with short-time workers send monthly reports to the office of the Federal Employment Agency in their district.[14] These reports contain a list of the firm's short-time workers in the previous months, their names and social security numbers, their reduction in working hours, their regular earnings, and the amount of short-time compensation that each worker is entitled to.[15] Some larger employers report their short-time work take-up electronically, but the majority of employers send typewritten reports. All typewritten reports submitted to the Nuremberg district of the Federal Employment Agency between June 2008 and December 2010 were digitized. These digitized reports and the electronically submitted lists from larger employers make up our first dataset.[16]

This dataset contains information on each individual worker's short-time work take-up including the number of reduced hours, regular earnings, and short-time compensation received. The dataset does not contain information on workers' regular working hours. However, we infer each short-time worker's regular hours based on the amount of short-time compensation assessed, the number of reduced hours worked, and the worker's regular earnings.[17]

[13]Throughout, we will refer to a short-time worker's "regular earnings" as the earnings that are used to assess the amount of short-time compensation a worker receives. Similarly, we will refer to a short-time worker's "regular hours" as the number of hours that this worker worked prior to the short-time work spell.

[14]The Federal Employment Agency has divided Germany into 178 districts and firms interact with the branch of the Federal Employment Agency in their district.

[15]Based on these reports, the Federal Employment Agency then transfers the total amount of short-time compensation to the employer and workers receive their pro-rated earnings and short-time compensation through their employer's payroll system.

[16]This dataset was previously used in Scholz (2012). See Scholz for more information on how the data were collected.

[17]We consider this measure to be a fairly accurate approximation of the worker's regular hours. It may not be fully correct, because it is possible that some workers may have agreed to a temporary reduction in total

In the raw data, we have information on 58, 181 short-time workers and 391, 801 months of short-time work. In total, we observe 1, 905 employers with at least one short-time worker between June 2008 and December 2010. This dataset includes all monthly short-time work reports submitted to the Federal Employment Agency in Nuremberg. However, it does not necessarily include the records for every short-time worker who lived or worked in the Nuremberg area. Firms that manage their payroll outside of Nuremberg may have submitted these reports to a different branch of the Federal Employment Agency. We address this potential shortcoming of our dataset below.

The second data source consists of the universe of German social security records made available by the IAB in its *Integrated Employment Biographies* (IEB).[18] The IEB contain information for all individuals who are employed subject to social security contributions (which excludes civil servants and the self-employed) and individuals who receive unemployment insurance or social assistance. From the universe of German social security records, we select every individual with at least one employment or unemployment spell in the Nuremberg area between January 2000 and December 2014. For each individual, we observe the entire employment biography starting in 1975 up until 2014. For any given month between 2000 and 2014, approximately 750,000 individuals show up in the data as residing in the Nuremberg metropolitan area.

The employment biographies are spell data and can contain multiple spells per person. We observe all work and unemployment spells, wages, age, gender, industry, occupation, vocational training, and education. Earnings data are reported before taxes and capped at the social security contribution threshold (which corresponds to monthly earnings of EUR 5, 950 in 2014). Since the employment biographies go back to 1975, we can construct a measure of labor market experience for each worker. For employed workers, we observe an employer identifier (at the establishment level), which allows us to create a measure of tenure. The employment biographies notably do not contain any information on short-time compensation or — more generally — on hours worked.[19]

We transform the spell data into a monthly panel. For each month, we classify individuals as full-time employed, part-time employed, unemployed, or out of the labor force. For workers who have multiple concurrent spells, we use the spell that accounts for the majority of the worker's earnings to assess the employment status. We link workers' employment biographies to our first dataset of short-time workers in the Nuremberg area. The merged dataset contains all workers in the Nuremberg metropolitan area with each worker's full employment biography and detailed information on short-time work take-up between June 2008 and December 2010.

compensation as part of a short-time work arrangement, in which case we would overstate regular working hours.

[18]The IEB are the source of the Sample of Integrated Labor Market Biographies (SIAB), the 2% sample of German social security records commonly used by researchers.

[19]The only information on hours that we observe is a part-time dummy, whose exact definition varies over time.

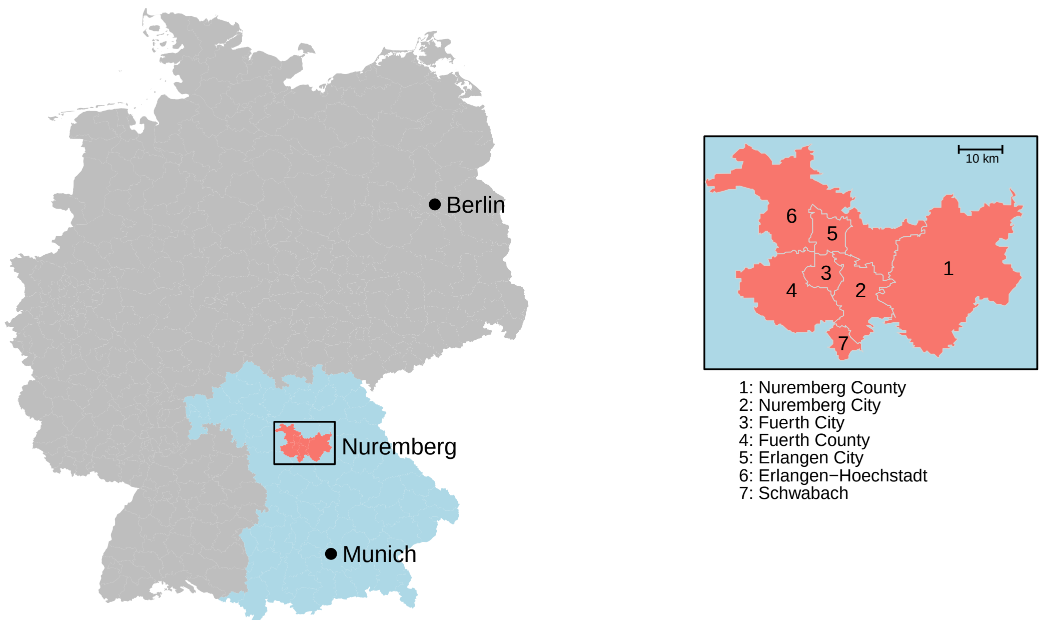


Figure 1: Metropolitan Area of Nuremberg

Note: The figure on the left shows a map of Germany with the metropolitan area of Nuremberg shown in red. The state of Bavaria is shown in blue. The figure on the right shows a map of the metropolitan area of Nuremberg as we define it.

The third data source contains establishment-level data collected and maintained by the Federal Employment Agency.[20] It contains the entire population of German firms with data on the number of short-time workers at the establishment level and the average reduction in hours due to short-time work. This information is recorded on a monthly basis and covers the time period from January 2009 to March 2011. We merge this dataset with our other data sources using a unique establishment identifier. We use this employer-level information to address measurement error concerns. As mentioned previously, the Nuremberg worker-level data underreport the short-time status of workers if their employers reported short-time work take-up to a branch of the Federal Employment Agency outside of Nuremberg.

Combined, these three data sources contain the universe of workers and firms in the metropolitan area of Nuremberg with detailed information on short-time compensation utilization at both the individual worker and the firm level. The dataset used in this paper is unique as it is the only dataset for Germany that combines information on short-time work with individual-level employment and earnings data.

	Mean	SD	p25	p50	p75	N
Experience	13.57	9.40	5.33	12.08	20.75	4,541,738
Tenure	7.10	7.37	1.50	4.33	10.33	3,983,728
Occupation Tenure	8.28	8.10	1.83	5.42	12.83	3,983,728
Earnings	3,109.65	1,347.36	2,124.72	2,904.01	4,023.51	3,984,362
Age	40.63	11.15	31.00	41.00	49.00	4,541,738
Female	0.38	0.48	0.00	0.00	1.00	4,541,738
Manufacturing	0.31	0.46	0.00	0.00	1.00	3,974,890

Table 2: Summary Statistics

Note: The summary statistics refer to a snapshot taken at January 1 for each year between 2000 and 2014. The sample is restricted to individuals who live in the Nuremberg area and are ages 19 to 65. By construction, the sample does not include civil servants or the self-employed.

3.2 The Nuremberg Labor Market

The Nuremberg district of the Federal Employment Agency is predominantly urban and is composed of the city of Nuremberg, the city of Erlangen, the city of Fuerth, and surrounding areas, which we show in Figure 1. In 2009, this district had a population of about 1.2 million.[21] About one third of the work force is employed in manufacturing.[22]

We select all individuals with their main place of residence in the Nuremberg metropolitan area.[23] We restrict the data to individuals with at least one full-time employment spell in the previous 24 months. We thereby exclude individuals who are not attached to the labor force. We further exclude individuals who are younger than 25 and those who are older than 60. By 25, the vast majority of individuals have completed schooling. As of age 60, many individuals begin to retire. Since both — schooling and early retirement — are not central to our paper, we choose to avoid dealing with these issues.[24] After this selection, we are left with about 300,000 individuals on a monthly basis. Throughout the time period that we consider, people enter and leave the Nuremberg area. For individuals who enter the Nuremberg area, we observe their full employment biography prior to entering the Nuremberg area, which we use to construct workers' employment histories including experience and tenure. For individuals who leave the Nuremberg area, we continue following these workers when we report long-run outcomes.

[20] Kruppe and Scholz (2014) also use this data source and then merge it with the Establishment Panel, a firm-level survey dataset.

[21] These districts are redrawn on a regular basis. We use the geographic definitions from 2009 throughout this paper. The Nuremberg district includes Nuremberg, Erlangen, Fuerth, Schwabach, and some parts of Roth. For our analysis we exclude the county of Roth. Employment agency districts were redrawn in January 2013. Today's Nuremberg district is substantially smaller.

[22] Items manufactured in the Nuremberg area include electrical equipment, mechanical and optical products, and motor vehicle parts.

[23] Alternatively, we could have selected individuals based on their place of work. However, using the place of residence allows us to use the same clearly defined sample definition for unemployed and employed workers. This avoids changes in the composition of the data due to changes in labor supply.

[24] Even though we drop observations for individuals younger than 25, we still use data on these spells to inform our measures of work experience and tenure.

Table 2 contains summary statistics from 2000 to 2014. For each of the 15 years in our data, we take a snapshot on January 1. The average person is approximately 41 years old with 12 years of work experience and 7 years of tenure. Median earnings before taxes equal about EUR 2,904 (inflation adjusted with base year 2010).

In Figure 2, we show the unemployment and short-time rates for Germany and Nuremberg. We construct the unemployment and short-time rates by dividing the total number of unemployed and short-time workers, respectively, by the total number of individuals who are attached to the labor force. The time series for the Nuremberg data is based on the data sources described above. The time series for Germany are constructed using the *Sample of Integrated Labour Market Biographies* (SIAB), a 2% sample of the IEB for the entire country. We obtain the total number of short-time workers from the aggregate short-time work statistics published by the Federal Employment Agency.[25]

Short-time work take-up in Nuremberg closely mirrors that of the rest of the country. Short-time work begins to increase in late 2008, then peaks at about 7.5% in the first half of 2009, and subsequently decreases to almost zero by the end of 2010. Even though the information on short-time work in our dataset is limited to the time period between June 2008 and December 2010, the aggregate data suggest that our dataset covers the relevant time period. While the short-time rates for Germany and Nuremberg look very similar, the Nuremberg unemployment rate is consistently lower than the nation-wide average. The make up of the Nuremberg labor force differs from Germany as a whole, as Nuremberg relies more heavily on manufacturing and its labor force tends to be slightly younger and more educated than the rest of the country.

Short-time work predominantly affected workers in manufacturing. In manufacturing, 10% of the entire workforce took up short-time work in the first half 2009. However, even among workers in manufacturing, there exists substantial heterogeneity in short-time work utilization. Within manufacturing, we observe a wide range of industries including industrial machinery, metal production, motor vehicle parts, electrical equipment, transportation, information technology and computer services. In addition, we observe a wide variety of occupations that are affected by short-time work including production workers and white collar back office staff.

Figure A1 in the Appendix shows the distribution of durations for both short-time work and unemployment spells that started between June 2008 and December 2010. Short-time work spells tend to be shorter than unemployment spells. Figure A2 in the Appendix shows the distribution of weekly short-time hours, i.e. the number of hours for which workers received short-time compensation. The average reduction in hours equals a little over 10 hours per week.

[25]This number is based on firm-level aggregates and includes all types of of short-time work, not just short-time work for economic reasons. For instance, take-up of seasonal short-time work during the winter months is visible in the graph.

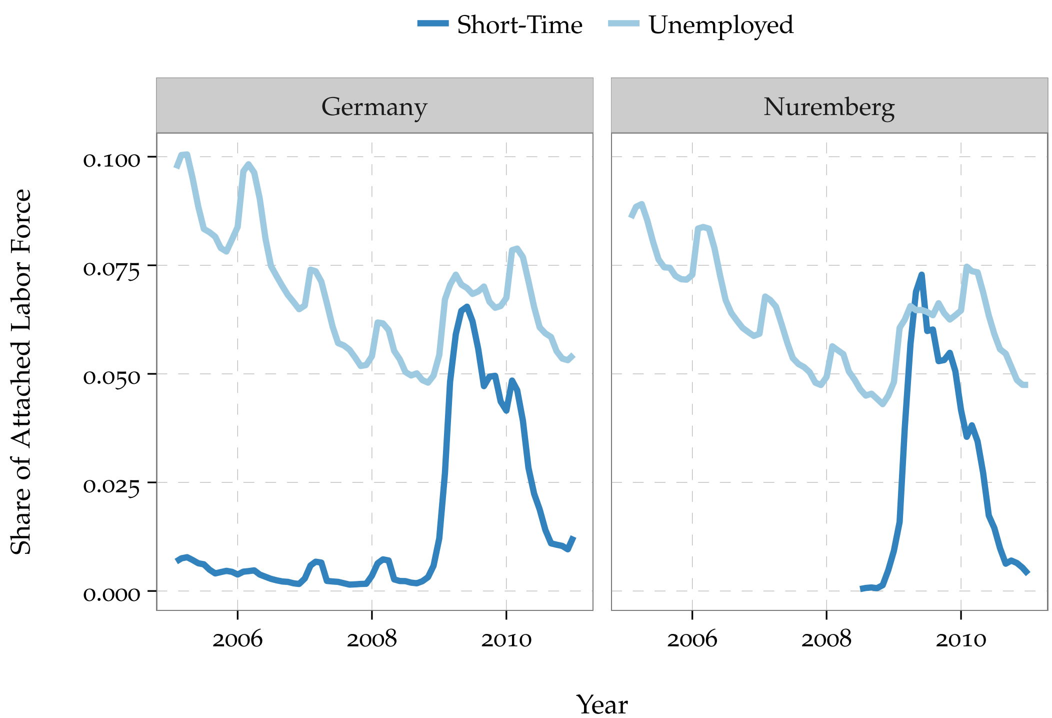


Figure 2: Unemployment and Short-Time Rates in Germany and Nuremberg

Note: The left panel shows the unemployment and short-time rates for Germany. The unemployment rate is based IAB, the 2% sample of the *Integrated Employment Biographies*. The short-time rate is based on the aggregate number of short-time workers as published by the Federal Employment Agency divided by the attached labor force that is taken from the SIAB. This aggregate short-time rate includes both seasonal and business cycle short-time work. The right panel shows the unemployment and short-time rates for Nuremberg as reported in the data. The short-time series excludes seasonal short-time work and underreports the true extent of short-time take-up, because some firms report their short-time workers to branches of the Federal Employment Agency other than Nuremberg. In the Nuremberg data, we only observe short-time status between June 2008 and December 2010.

In our worker-level data, short-time take-up is underreported. We only have short-time records for employers in the Nuremberg area that reported short-time utilization to the Nuremberg district of the Federal Employment Agency. Some employers that do their payroll processing outside of Nuremberg may have reported their short-time utilization to a different district. Therefore, some of the workers we classify as full-time employed may in fact be short-time workers. To quantify the extent of the measurement error we rely on an additional establishment-level data source that covers the period from January 2009 to March 2011. This dataset has an accurate count of short-time workers (and the average reduction in hours) at the establishment level. We find that between January 2009 and December 2010, the true number of short-time worker-months is about 15% higher than reported in our worker-level dataset.

3.3 Facts about Short-Time Work

We proceed by documenting three facts about short-time work. Throughout we focus on 2009, the year that accounts for the vast majority of short-time take-up. First, short-time take-up is increasing in experience and tenure — even after accounting for a large number of other observables. Second, the vast majority of short-time workers return to full-time work with their current employer. Third, short-time workers experience a temporary but not a long-term loss in earnings.

In Figure 3, we plot the unconditional month-to-month transition probabilities of moving from full-time work to short-time work and from full-time work to unemployment for 2009. Short-time work is strongly increasing in experience and tenure. In the data, individuals with less than two years of experience have a month-to-month transition probability into short-time work of about 0.005. For individuals with two to five years of experience, that probability doubles to about 0.010. For individuals with more than 20 years of experience, that probability doubles again to about 0.020. Similar patterns emerge for different lengths of tenure. Workers with less than two years of tenure have a transition probability into short-time work of about 0.006. Individuals with 10 to 20 years of tenure have a transition probability of 0.020. Individuals with more than 20 years of tenure have a transition probability of short-time work of 0.028. In contrast, transitions into unemployment are strongly decreasing in experience and tenure.

What happened to workers after a short-time work spell? In the left panel of Table 3, we show the destinations of all short-time workers in the data once their short-time spell ends. We focus on workers' initial short-time spell in the data. The vast majority of short-time workers, 95.7%, return to full-time work without switching employers. On average, these workers spend 5.65 months in short-time work. Only 2.1% of short-time workers switch jobs from short-time work to employment with a different employer. A negligible fraction (0.6%) of short-time workers transitions from short-time work into unemployment. The number of short-time workers who either leave the dataset (i.e. leave the labor force or accept a job that

Figure 3: Short-Time and Unemployment Hazard as a Function of Experience and Tenure

Note: The left panel shows the month-to-month transition probability from full-time work to short-time work for 2009 as a function of experience and tenure. The right panel shows the month-to-month transition probability from full-time work to unemployment for 2009 as a function of experience and tenure. Short-time work is positively correlated with experience and tenure; unemployment is negatively correlated with experience and tenure.

	Short-Time Workers			Unemployed Workers		
	Count	%	Duration	Count	%	Duration
Total	51,803	100.0	5.64	124,313	100.0	6.82
Full-Time (Same Firm)	49,562	95.7	5.65	14,117	11.4	4.73
Full-Time (Switch)	1,108	2.1	5.02	68,142	54.8	6.46
Part-Time	287	0.6	7.94	15,224	12.2	7.89
Short-Time				88	0.1	5.90
Layoff	315	0.6	4.38			
Leave Data Temporarily	440	0.8	5.62	19,544	15.7	7.70
Leave Data Permanently	91	0.2	7.41	7,198	5.8	9.78

Table 3: Transition Out of Short-Time Work and Unemployment

Note: The left panel of the table breaks down the destination of short-time workers in the data. The rows refer to the destination after the end of the initial short-time spell between June 2008 and December 2010. The table on the right breaks down all initial unemployment spells by destination for the same time period. In both panels, the duration column refers to months spend in short-time work or unemployment before the destination was reached.

is not subject to social security contributions) or switch to part-time employment is 1.6%.

In contrast, the picture looks very different for workers who were laid off. In the right panel of Table 3 we show the destinations of all laid off workers in the data once their unemployment spell ends. We limit our attention to unemployment spells that began between June 2008 and December 2010. Among the laid off, about 11% return to a previous employer to work in full-time employment. Workers who are recalled spend on average 4.7 months in unemployment. About 55% of laid off workers transition into full-time employment with an employer for whom they have not worked before. Such a transition occurs after an average of about 6.5 months. Among the laid off workers, a large fraction (12.2%) switch to part-time employment, while 21.5% leave the data. Table 3 indicates that short-time work presents only a temporary — though non-negligible — interruption to a worker's career.

We now turn to the longer-run consequences of short-time work. We select all individuals who are employed full-time in January 2009 with at least six months of tenure in their current job. We then follow these individuals over time and compare how full-time employment and earnings evolve in response to an initial transition into either short-time work or unemployment. As in much of the literature on scarring effects, we drop all individuals who have not returned to full-time work for at least six months by December 2014. We focus on two different measures of earnings. The first measure is gross labor earnings, which we set to zero for individuals who are unemployed. The second measure is imputed after-tax earnings plus transfers, which are equal to after-tax labor earnings for the full-time employed, equal to after-tax labor earnings plus short-time compensation for short-time workers, and equal to unemployment insurance benefits for the unemployed.[26]

[26]When we compute after-tax earnings we use a conservative approach and treat every person as a single household with labor earnings as the only source of income. The reason we compute after-tax earnings is that short-time compensation and unemployment insurance are assessed on a worker's after-tax income. Therefore, to assess the impact that a short-time or unemployment spell has on a worker's total earnings, we need to use consistent measures for earnings in the labor market and government transfers such as unemployment insurance

We index calendar time by t, where $t = 0$ refers to January 2009. We define the variables τ_i^S and τ_i^U to refer to the time period when individual i initially transitioned from full-time work to short-time work and from full-time work to unemployment. When no such transition occurred between January 2009 and December 2014, we set the respective variable to negative one.

To capture the long-run consequences of short-time work and unemployment on future full-time employment, we estimate the statistical model

$$y_{it} = \sum_{s=0}^{T} \alpha_s \times \mathbf{1}\{t - s = \tau_i^U\} + \sum_{s=0}^{T} \beta_s \times \mathbf{1}\{t - s = \tau_i^S\} + X_{it}'\mu + \gamma_t + \xi_i + \varepsilon_{it},$$

where y_{it} equals one if worker i works full-time in period t and equals zero otherwise. The coefficient α_s captures the effect of a transition to short-time work at time $t - s$ on full-time employment at time t. Similarly, β_s captures the effect of a layoff at time $t - s$ on full-time employment at time t. The coefficient γ_t refers to monthly calendar time dummies. X_{it} is a vector of time-varying worker-specific covariates. ξ_i is a person fixed effect.

In the left panel of Figure 4, we show the coefficient estimates for α_s and β_s. Initially, both a transition into short-time work and a transition into unemployment are associated with a large decrease in the probability of full-time employment. The estimates for α_s and β_s only diverge after about five months. Short-time workers return to full-time work faster. After ten months, short-time work only reduces the probability of full-time employment by about 20 percentage points, whereas unemployment reduced the probability of full-time by more than 30 percentage points. After about 18 months, there is no detectable effect of short-time work on full-time employment. In contrast, unemployment has a long-lasting effect on full-time employment even after 48 months.[27] In the long-run, the gap in full-time employment between workers who were laid off at time zero and those who transitioned to short-time work at time zero is about 15 percentage points.

We observe similar patterns for individuals' after-tax earnings. To assess the effects on earnings, we employ the following statistical model of earnings:

$$\log w_{it} = \sum_{s=0}^{T} \alpha_s \times \mathbf{1}\{t - s = \tau_i^U\} + \sum_{s=0}^{T} \beta_s \times \mathbf{1}\{t - s = \tau_i^S\} + X_{it}'\mu + \gamma_t + \xi_i + \varepsilon_{it},$$

where w_{it} is the sum of an individual's after-tax earnings and transfers at time t. For short-time workers, w_{it} refers to the sum of after-tax wage earnings and total short-time compensation received. For unemployed workers, w_{it} refers to the amount of unemployment insurance that

benefits and short-time compensation.

[27] Notice that for short-time workers, the coefficient estimates for α_s turn positive after about 22 months implying that short-time workers have a *higher* probability of working full-time than individuals who were not put on short-time work or laid off at time 0.

Figure 4: Evolution of Full-Time Employment by Experience

Note: The graphs show the probability of full-time work for individuals who transitioned from full-time employment to short-time work or unemployment at time zero.

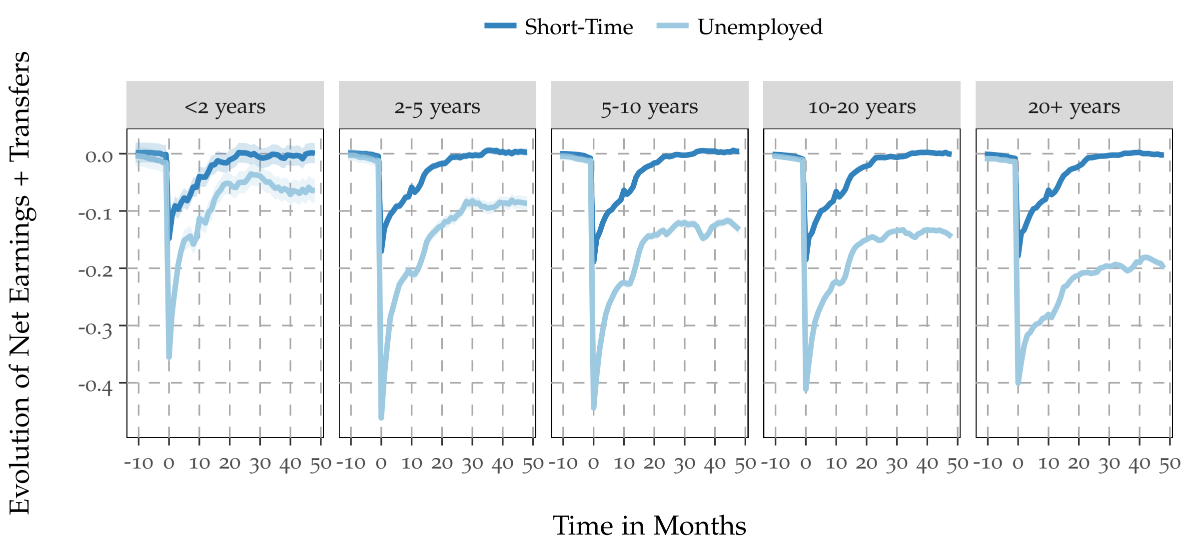


Figure 5: Evolution of Earnings

Note: The graphs show the change in earnings for individuals who transitioned from full-time employment to short-time work or unemployment at time zero.

workers receive.[28]

In Figure 5, we plot the estimates for α_s and β_s. The initial drop in after-tax earnings plus transfers for short-time workers is about 15%, while the initial drop in after-tax earnings plus transfers for unemployed workers is about 45%. Short-time workers catch up with their peers after approximately 18 months and subsequently outperform them. Even four years after the initial layoff, unemployed workers do not catch up. The results look qualitatively similar when we use gross earnings without accounting for transfers. The results indicate that short-time workers do not face negative long-term consequences from the short-time spell. However, the initial loss in earnings is substantial.

4 Model

In this section, we introduce an equilibrium life-cycle model with search frictions that is consistent with the facts presented in Section 3. The labor market in the model is subject to search frictions. The unit of analysis is the firm-worker match. The benefit of ignoring the interaction between workers at the same firm is that our model allows us to focus on worker-level heterogeneity and the impact of unemployment and short-time work on individual workers' careers.

The essence of short-time work is to provide financial support in response to *temporary* productivity shocks. During recessions, some workers are temporarily unprofitable at their current firm, but are likely to be profitable again in the future. Short-time compensation provides financial incentives that prevent these workers from being laid off. Our model features match-specific productivity shocks that differ in expected duration. The duration of match productivity interacts with the aggregate productivity state of the economy. In recessions, productivity shocks tend to be worse in magnitude and shorter in duration than during normal economic times.

Since we model how workers and firms respond to temporary productivity shocks, we part with the usual assumption in search models that once a worker and firm separate, they will never meet again. Instead, we follow Fujita and Moscarini (2016) and allow unemployed workers to be recalled by their most recent employer whenever this is mutually beneficial. This means that workers and firms can use the traditional unemployment insurance system to deal with temporary productivity shocks by laying workers off temporarily and then rehiring the same workers back after the recession.

In the data, unemployment insurance benefits is a function of the worker's most recent earnings. Short-time compensation is a function of the worker's current earnings. Workers in high wage jobs therefore receive higher benefits. Modeling these institutional features is

[28]For workers who ran out of unemployment insurance benefits, w_{it} refers to an imputed measure of social assistance.

important to accurately reflect the trade-offs associated with continued employment, short-time work, and unemployment. In the model a worker receives short-time compensation and unemployment insurance benefit as a function of her regular earnings.

We establish a notion of regular earnings in our model by introducing *simple* wage contracts. Such a wage contract defines the worker's hourly wage as a function of the worker's human capital. These wage contracts are otherwise fully rigid and cannot be changed throughout an employment relationship. Most importantly, the wage contracts *cannot* be flexibly adjusted in response to temporary productivity shocks. Restricting the contract space in this way is motivated by the casual observation that wages for ongoing matches do not downward adjust in recessions; see, e.g., Bewley (1999) for a general treatment that focuses on the U.S., and Franz and Pfeiffer (2006) for a survey on the German labor market in particular. Many theories have been put forward to understand why wages do not flexibly adjust during downturns (Ramey and Watson (1997), Fehr and Falk (1999), Menzio and Moen (2010) and others). We make no attempt to generate wage rigidities endogenously. Instead, we impose the mere constraint that wage contracts of existing matches cannot be a function of the current productivity state. The only flexible form of adjustment that we allow for is a change in working hours. Our notion of rigidity only applies to existing contractual relationships. Wages of new hires can adjust flexibly and are lower in recessions than during normal times.

We allow workers to differ along three dimensions: age, general human capital, and firm-specific human capital. All three components are important to understand how workers and firms respond to temporary productivity shocks. All three components also shape a worker's life-cycle employment and earnings profile. Workers accumulate general and firm-specific human capital while working. General human capital depreciates during spells of unemployment. Firm-specific human capital is lost the moment a worker begins working at a different firm. Age matters because retirement imposes an upper bound on the horizon of an employment relationship.

Aggregate shocks render our environment non-stationary. This in turn makes it both conceptually and computationally challenging to allow for rich amounts of worker heterogeneity, such as age and different forms of human capital. We therefore follow Menzio and Shi (2011) and model search in the labor market as directed. Firms post jobs and workers — after observing all available jobs — decide where to search. This has the benefit that workers will never apply for jobs they are unwilling to accept. This will later permit us to characterize the equilibrium of the model without having to keep track of the entire distribution of workers across states.

4.1 Environment

Time is discrete, indexed by t, and lasts forever. There is an aggregate productivity shock z_t that can take on one of two values $\mathcal{Z} = \{\underline{z}, \overline{z}\}$, where $\underline{z}$ refers to recessions and $\overline{z}$ to normal economic times. The evolution of z follows a Markov process, the distribution of which we denote by $\Lambda(z_{t+1}|z_t)$. When there is no ambiguity, we drop the subscript t and denote variables that refer to a subsequent period by a prime.

The economy is populated by $A \geq 2$ overlapping generations of workers. Every period, a new generation of workers is born. Each worker lives for A periods and then retires. Each worker is endowed with one divisible unit of labor. Workers have per-period preferences over consumption, c, and hours worked, h, given by $u(c,h)$, where $u : \mathbb{R}_+ \times [0,1] \mapsto \mathbb{R}$ is strictly increasing in c and strictly decreasing in h. Workers discount the future with discount factor β. There are no savings. In each period, workers consume all of their income.

A worker is characterized by her type $\mathbf{x} = [x_a, x_g]$, where $x_a \in \{1, \ldots, A\}$ refers to the worker's age and $x_g \in \mathcal{X}_g$ refers to the worker's *general* human capital. General human capital, x_g, is fungible and can be transferred from firm to firm. General human capital takes on values on the discrete set $\mathcal{X}_g = [x_g(1), \ldots x_g(K)]$, where $K \geq 2$ is an integer and $x_g(K) > x_g(K-1) > \cdots > x_g(1)$. We model $\mathcal{X}_g$ as a ladder. From one period to the next, a worker can move by at most one rung along the ladder. Transitions on the ladder are stochastic and depend on hours worked. Working more hours make transitions up the ladder more likely. Working fewer (or zero) hours make transitions down the ladder more likely. We denote the transition distribution function of the worker's entire type vector by $\Omega_x(\mathbf{x}'|\mathbf{x}, h)$. The dependence on hours worked, h, makes explicit that the transition of general human capital is a function of hours worked. For future reference, we denote the set of worker types by $\mathcal{X} = \{1, \ldots, A\} \times \mathcal{X}_g$.

The economy is populated by a positive measure of firms. Firms are risk-neutral, maximize profits, and discount the future with factor β. To produce output, a firm needs to be matched with a worker. We denote a firm's type by $\mathbf{y} = [y_s, y_m, y_p]$, which consists of the worker's *firm-specific* human capital $y_s \in \mathcal{Y}_s$, and the magnitude $y_m \in \mathbb{R}$ and persistence $y_p \in [0,1]$ of match-specific productivity. Flow output is given by

$$f(x_g, y_s, y_m) \times h,$$

where $f : \mathcal{X}_g \times \mathcal{Y}_s \times \mathbb{R} \times [0,1] \mapsto \mathbb{R}_+$ is strictly increasing in all of its arguments and h refers to hours worked. From the outset, we assume that the firm's production function is linear in hours worked. To simplify notation, we refer to $f(x_g, y_s, y_m)$ as $f(\mathbf{x}, \mathbf{y})$.

In contrast to general human capital, firm-specific human capital cannot be transferred from one firm to the next. The evolution of firm-specific human capital, y_s, is modeled in a similar fashion as the evolution of general human capital. Firm-specific human capital takes on values on the discrete set $\mathcal{Y}_s = [y_s(1), \ldots, y_s(L)]$, where $L \geq 2$ is an integer and $y_s(L) > y_s(L-1) > \cdots > y_s(1)$. Transitions on the ladder are stochastic and depend on hours worked.

One of the model's key ingredients is a theory of temporary fluctuations, in which productivity shocks differ in magnitude and duration. The magnitude of match-specific productivity, y_m, follows a jump process. With probability y_p, the vector of match productivity $[y_m, y_p]$ remains unchanged from one period to the next. With probability $1 - y_p$, the firm-worker pair draws a new vector of match productivity $[\tilde{y}_m, \tilde{y}_p]$ from the distribution $\Gamma(\tilde{y}_m, \tilde{y}_p|z)$. Formally, we assume that

$$[y_m{}', y_p{}'] = \begin{cases} [y_m, y_p] & \text{with probability } y_p \\ [\tilde{y}_m, \tilde{y}_p] & \text{with probability } 1 - y_p. \end{cases} \quad (1)$$

The aggregate productivity state does not affect match productivity directly.

This jump process is an important ingredient of the model. The productivity process introduces heterogeneity in the persistence of shocks. Some matches are hit by productivity shocks that are almost permanent, which means that short-time work is not an interesting option. Others are hit by productivity shocks that are temporary, making short-time work an attractive option. The productivity process also implies that firms and workers are aware of the persistence of the shock they are experiencing at any given point in time. This is important, because otherwise firms and workers would not be able to act on it. Furthermore, the persistence of productivity shocks may differ in normal times and recessions, which will allow the model to capture the incidence and duration of short-time work. Another feature of the assumed productivity process is that recessions do not necessarily affect all workers directly. It is only when a firm-worker pair draws a new productivity shock — which happens with probability y_p — that the worker experiences the immediate consequences of the recession. The model allows for a share of the workforce to not experience the direct consequences of the recession, simply because they do not draw a new productivity shock during the time period when $z = \underline{z}$.

For future reference, we denote the set of firm types by $\mathcal{Y} = \mathcal{Y}_S \times \mathbb{R}_+ \times [0, 1]$. We denote the transition distribution function of the firm's entire type vector by $\Omega_y(\mathbf{y}'|\mathbf{y}, h, z)$. We refer to the distribution from which initial values are drawn by $\Gamma(\mathbf{y}|z)$.

Firms and workers need to determine wages and hours. We assume that an employment relationship is governed by a simple contract that we denote by $w : \mathcal{X}_g \times \mathcal{Y}_s \mapsto \mathbb{R}_+$. We define the set of wage contracts as $\mathcal{W}$. This contract specifies the *hourly* wage as a function of the worker's human capital. To simplify notation, we refer to the wage implied by a contract w as $w(\mathbf{x}, \mathbf{y}) = w(x_g, y_s)$. As the worker's general or firm-specific human capital changes, compensation may change as well. We assume that hours are unilaterally determined by the firm.

While the wage contract is fixed and cannot be changed, workers are free to quit at any time and firms are free to lay workers off at any time. Our simple contracts are by no means optimal. However, they provide a reasonable approximation, fit the data well, and allow us to precisely model the generosity of short-time work and unemployment insurance.

Workers search for jobs on and off the job. Search is directed and the labor market is segmented by worker type. Firms post wage contracts w that target a particular worker type. A worker observes all posted wage contracts for her type and then decides which wage contract to search for. The probability that a searching worker meets a firm depends on the market tightness in the submarket in which the worker is searching.

Both unemployed and employed workers search for jobs, but they differ in their search efficiency. We assume that workers' efficiency units of search depend on hours worked. The more time a worker spends at work, the less efficient she is at searching. We denote the efficiency units by $\lambda : [0, 1] \mapsto [0, 1]$, which is a monotonically decreasing function that maps hours worked into search efficiency units. We normalize the efficiency units of an unemployed worker by imposing that $\lambda(0) = 1$.

Let the total measure of efficiency units of search exerted in a particular submarket be given by $\mathcal{U} \geq 0$ and the total measure of vacancies posted in this submarket by $\mathcal{V} \geq 0$. Searching workers and vacancies are brought together by a matching function, $M : \mathbb{R}_+ \times \mathcal{W} \mapsto \mathbb{R}_+$, that maps the measure of efficiency units of search and the measure of vacancies into meetings. We assume that M is strictly increasing in both arguments and equals zero if one of its arguments is zero. Furthermore, we assume that M exhibits constant returns to scale. Therefore, the total measure of meetings per efficiency unit of search is given by

$$\frac{1}{\mathcal{U}} M(\mathcal{U}, \mathcal{V}) = M(1, \frac{\mathcal{V}}{\mathcal{U}}).$$

The total measure of meetings generated only depends on the ratio $\frac{\mathcal{V}}{\mathcal{U}}$, which is the tightness of the submarket and we refer to it as θ. We define $p(\theta) = M(1, \theta)$, where $p : \mathbb{R}_+ \mapsto \mathbb{R}_+$ and p inherits its properties from M. As mentioned above, a worker's efficiency units of search depend on the worker's hours worked. The probability that a worker who works h hours meets a firm in this particular submarket is given by $\lambda(h)p(\theta)$.

The total measure of meetings per vacancy is given by

$$\frac{1}{\mathcal{V}} M(\mathcal{U}, \mathcal{V}) = \frac{\mathcal{U}}{\mathcal{V}} M(1, \frac{\mathcal{V}}{\mathcal{U}}).$$

We define $q(\theta) = M(\theta)/\theta$, where $q : \mathbb{R}_+ \mapsto \mathbb{R}_+$ and q inherits its properties from M. The measures of searching workers and posted vacancies are endogenous objects that we characterize below.

In the model, there are two types of unemployment. Some workers are permanently unemployed. The only way for these workers to return to full-time work is by finding a new employer. Some workers are temporarily laid off. These are workers for whom the employer has chosen zero working hours. These workers may — in addition to searching for jobs with other firms — be recalled by their previous employer whenever this is mutually beneficial to the worker and the firm. For the purpose of modeling temporary layoffs, we treat these workers as employed at zero working hours. While temporarily unemployed, match productivity keeps evolving. Also, the worker's general and firm-specific human capital keeps evolving. Recall is not perfect. A worker who is currently working h hours loses contact with her employer for exogenous reasons with probability $\delta(h)$, where $\delta(h)$ is decreasing in h. When a temporarily laid off worker loses contact, the worker becomes permanently unemployed.

When a worker and a firm initially meet, the worker's firm-specific human capital is initialized at the bottom rung of the human capital ladder. Furthermore, we assume that the initial values of $[y_m, y_s]$ are only a function of the aggregate productivity state z. We denote the initial value by $\mathbf{y}_0(z)$. Workers are perfectly aware of the match quality when they search for a job. Therefore, workers will accept all jobs they search for. The benefit of making this assumption is that firms need not keep track of the distribution of workers when they compute the value of posting a vacancy. Firms know that any worker they meet will accept the offer. Alternatively, we could assume that matches are experience goods, an assumption entertained in Menzio and Shi (2011), in which workers only learn the quality of a match after accepting it.

We consider two labor market policies: unemployment insurance and short-time compensation. With unemployment insurance, a worker receives a fraction of her most recent full-time compensation. An unemployed worker's consumption level is therefore equal to her most recent full-time compensation multipled by a replacement rate. We denote the most recent full-time compensation by r. We allow unemployment insurance benefits to expire at a fixed rate at which point the reference wage r drops to $\underline{r}$. With short-time compensation, a worker receives a fraction of her contractually agreed full-time compensation for any hours *not* worked, i.e. a worker's total consumption equals

$$\underbrace{w(\mathbf{x}, \mathbf{y}) \times h}_{\text{paid by firm}} + \underbrace{\text{replacement rate} \times w(\mathbf{x}, \mathbf{y}) \times (1-h)}_{\text{short-time compensation}}$$

We consolidate both policy instruments, unemployment insurance and short-time work, into a benefit function $b : \mathbb{R}_+ \times [0,1] \times [\underline{z}, \overline{z}] \mapsto \mathbb{R}_+$, which maps the current or most recent hourly wage, hours worked, and the aggregate productivity state of the economy into the amount of benefits paid to the worker. We allow this function to depend on the aggregate productivity state to reflect that short-time compensation is only available in recessions.

Short-time compensation and unemployment insurance are funded through a payroll tax that is levied on firms. We denote the tax function by $\tau : \mathbb{R}_+ \times [0,1] \times [\underline{z}, \overline{z}] \mapsto \mathbb{R}_+$, which maps the hourly wage, hours worked, and the aggregate productivity state of the economy into the effective tax rate. We keep the function general and allow it to condition on the aggregate productivity state of the world.

4.2 Equilibrium

We now characterize the equilibrium of our economy. We denote the aggregate state of the economy at time t by $\boldsymbol{\zeta}_t = \left[z_t, g_t^0(\mathbf{x}, r), g_t^1(\mathbf{x}, \mathbf{y}, w)\right]$, which consists of aggregate productivity state z_t, the distributions of unmatched workers, $g_t^0 : \mathcal{X} \times \mathbb{R}_+ \mapsto [0, 1]$, and the distributions of matched workers, $g_t^1 : \mathcal{X} \times \mathcal{Y} \times \mathcal{W} \mapsto [0, 1]$. The distribution of unmatched workers keeps track of worker types $\mathbf{x}$ and their most recent full-time compensation r. The distribution of matched workers keeps track of worker types, $\mathbf{x}$, firm types, $\mathbf{y}$, and wage contracts, w. We denote the endogenous transition distribution function of the entire state vector $\boldsymbol{\zeta}_t$ by $\Lambda(\boldsymbol{\zeta}_{t+1}|\boldsymbol{\zeta}_t)$. To simplify the exposition, we drop the subscript t hereafter. Consider the value function of a permanently unemployed type-$\mathbf{x}$ worker with $\mathbf{x} \in \{1, \ldots, A-1\} \times \mathcal{X}_g$ whose most recent full-time wage equals r,

$$
\begin{aligned}
U(\mathbf{x}, r, \boldsymbol{\zeta}) = \max_{\tilde{w}} u(b(r, 0, z), 0) & \\
+ (1 - p(\theta(\tilde{w}, \mathbf{x}, \boldsymbol{\zeta})))\beta \mathbb{E}\left[U(\mathbf{x}', r', \boldsymbol{\zeta}')|h = 0, \mathbf{x}, \boldsymbol{\zeta}\right] & \\
+ p(\theta(\tilde{w}, \mathbf{x}, \boldsymbol{\zeta}))\beta \mathbb{E}\left[W(\mathbf{x}', \tilde{w}, \mathbf{y}_0, \boldsymbol{\zeta}', h')|h = 0, \mathbf{x}, \boldsymbol{\zeta}\right]. &
\end{aligned} \tag{2}
$$

This unemployed worker consumes unemployment insurance benefits $b(r, 0, z)$ and works zero hours, resulting in flow utility $u(b(r, 0, z), 0)$. The worker chooses which wage contract $\tilde{w}$ to search for. The market tightness in each submarket is given by $\theta(\tilde{w}, \mathbf{x}, \boldsymbol{\zeta})$. If the job search is unsuccessful, which occurs with probability $1 - p(\theta(\tilde{w}, \mathbf{x}, \boldsymbol{\zeta}))$, the worker will remain unemployed. The worker's state evolves to $\mathbf{x}'$ as the worker gets older and her human capital stock evolves. Also, the worker's most recent full-time wage may evolve to r' to account for the possibility that unemployment insurance benefits will expire.

If the job search is successful, which occurs with probability $p(\theta(\tilde{w}, \mathbf{x}, \boldsymbol{\zeta}))$, the worker enters the next period matched to firm $\mathbf{y}_0$ in wage contract $\tilde{w}$. In this case, the continuation value is $W(\mathbf{x}', \tilde{w}, \mathbf{y}_0, \boldsymbol{\zeta}', h')$, where h' refers to the firm's hours policy function $h(\mathbf{x}', \tilde{w}, \mathbf{y}_0, \boldsymbol{\zeta}')$ that we specify below. A worker who meets a firm will always form a match. Workers with different values of r will likely search for different wage contracts as they receive different amounts of unemployment insurance benefits. A worker with more generous unemployment insurance benefits may be more willing to search for higher wage contracts that entail a lower probability of meeting a firm.

Consider the value function of a type-$\mathbf{x}$ worker who works at a type-$\mathbf{y}$ firm in contract w. Furthermore, suppose that the firm has set hours worked to h. The worker's value from working is given by

$$
\begin{aligned}
W(\mathbf{x}, w, \mathbf{y}, \boldsymbol{\zeta}, h) = \max_{\tilde{w}} u(w(\mathbf{x}, \mathbf{y})h \, + \, b(w(\mathbf{x}, \mathbf{y}), h, z), h) \\
+(1 - \lambda(h) p(\theta(\tilde{w}, \mathbf{x}, \boldsymbol{\zeta}))) \beta \mathbb{E}\big[(1 - \delta(h)) W(\mathbf{x}', w, \mathbf{y}', \boldsymbol{\zeta}', h') \\
+ \delta(h) U(\mathbf{x}', r', \boldsymbol{\zeta}') | h, \mathbf{x}, \mathbf{y}, \boldsymbol{\zeta}\big] \\
\lambda(h) p(\theta(\tilde{w}, \mathbf{x}, \boldsymbol{\zeta})) \beta \mathbb{E}\big[(1 - \delta(h)) W(\mathbf{x}', \tilde{w}, \mathbf{y}_0, \boldsymbol{\zeta}', h') \\
+ \delta(h) U(\mathbf{x}', r', \boldsymbol{\zeta}') | h = 0, \mathbf{x}, \boldsymbol{\zeta}\big].
\end{aligned}
\tag{3}
$$

The continuation value depends on whether the worker's on-the-job search is successful. The worker chooses which wage contracts $\tilde{w}$ to search for. The probability that search is successful equals $\lambda(h)p(\theta(\mathbf{x}, \tilde{w}, \boldsymbol{\zeta}))$, where $\lambda(h)$ refers to the efficiency units of search. If search is successful, the worker will be matched to the new firm in the subsequent period with initial match quality $\mathbf{y}_0$. We assume that for switchers, general human capital evolves as if these individuals work zero hours. On the one hand, this is a technical assumption that allows us to simplify the computation of the equilibrium later on, because firms that post vacancies need not distinguish between workers who are currently employed and those who are not. On the other hand, this assumption has economic content and can be interpreted as the direct cost the worker incurs when switching jobs.

If search is not successful, which happens with probability $1 - \lambda(h)p(\theta(\mathbf{x}, \tilde{w}, \boldsymbol{\zeta}))$, then the worker will remain matched to her current firm with probability $1 - \delta(h)$ or become unmatched with probability $\delta(h)$. For future reference we denote the search policy function of the worker by $s(\mathbf{x}, w, \mathbf{y}, \boldsymbol{\zeta}, h)$, which returns the wage contract $\tilde{w}$ that the worker is searching for.

Next, consider the value functions of the firm. A type-$\mathbf{y}$ firm's value from employing a type-$\mathbf{x}$ worker for h hours in contract w equals

$$
\begin{aligned}
J(\mathbf{x}, w, \mathbf{y}, \boldsymbol{\zeta}, h) = [f(\mathbf{x}, \mathbf{y}) - w(\mathbf{x}, \mathbf{y})]h - \tau(w(\mathbf{x}, \mathbf{y}), h, z) \\
+(1 - \lambda(h) p(\theta(\tilde{w}, \mathbf{x}, \boldsymbol{\zeta}))) \beta \mathbb{E}\left[(1 - \delta(h)) J(\mathbf{x}', w, \mathbf{y}', \boldsymbol{\zeta}', h') | h, \mathbf{x}, \mathbf{y}, \boldsymbol{\zeta}\right],
\end{aligned}
\tag{4}
$$

where $\tilde{w}$ refers to the wage contract that worker $\mathbf{x}$ is searching for on-the-job, i.e. $\tilde{w} = s(\mathbf{x}, w, \mathbf{y}, \boldsymbol{\zeta}, h)$. The firm's value is the flow payoff, output minus wage bill and tax obligations, plus the continuation value.

We have yet to define the terminal value functions for workers and firms. The value function of an unemployed type-$\mathbf{x}$ worker with $\mathbf{x} \in \{A\} \times \mathcal{X}_g$ whose most recent full-time wage equals r is given by

$$
U(\mathbf{x}, r, \boldsymbol{\zeta}) = u(b(r, 0, z), 0) + \overline{U}(\mathbf{x}), \tag{5}
$$

where the worker's terminal value U is a function of the worker's human capital at the end of her working life. The value function of a type-$\mathbf{x}$ worker with $\mathbf{x} \in \{A\} \times \mathcal{X}_g$ is of the same form,

$$W(\mathbf{x}, w, \mathbf{y}, \boldsymbol{\zeta}, h) = u(w(\mathbf{x}, \mathbf{y})h + b(w(\mathbf{x}, \mathbf{y}), h, z), h) + \overline{W}(\mathbf{x}), \tag{6}$$

where the worker's terminal value W is a function of the worker's human capital at the end of her working life. The employed worker receives flow utility that depends on the wage contract, hours worked, and short-time compensation plus an expected terminal value that depends on the worker's general human capital and most recent full-time wage. For the firm, we assume that the terminal value is zero, i.e. it will only earn its flow profits in the terminal period.

$$J(\mathbf{x}, w, \mathbf{y}, \boldsymbol{\zeta}, h) = [f(\mathbf{x}, \mathbf{y}) - w(\mathbf{x}, \mathbf{y})]h - \tau(w(\mathbf{x}, \mathbf{y}), h, z). \tag{7}$$

The firm chooses the hours worked h, where a choice of $h = 0$ denotes a (temporary) layoff. Initially, all layoffs are temporary, but they become permanent with probability $\delta(0)$. The hours choice is given by

$$h \in \underset{\tilde{h} \in [0,1]}{\operatorname{argmax}} \, J(\mathbf{x}, w, \mathbf{y}, \boldsymbol{\zeta}, \tilde{h}) \quad \text{s.t.} \quad W(\mathbf{x}, w, \mathbf{y}, \boldsymbol{\zeta}, \tilde{h}) \geq W(\mathbf{x}, w, \mathbf{y}, \boldsymbol{\zeta}, 0). \tag{8}$$

A solution to this equation always exists, because an hours choice of 0 gives the worker at least the value of unemployment and thereby satisfies the constraint.

There is an infinite number of potentially entering firms. These firms can post vacancies at cost $\chi(\mathbf{x})$ and when they do, they can target a particular type of worker $\mathbf{x}$. The firm's value from posting a vacancy is given by

$$V(\boldsymbol{\zeta}) = \max_{w, \mathbf{x}} -\chi(\mathbf{x}) + q(\theta(w, \mathbf{x}, \boldsymbol{\zeta}))\mathbb{E}\left[J(\mathbf{x}', \mathbf{y}_0, w, \boldsymbol{\zeta}') \mid h = 0, \mathbf{x}, \boldsymbol{\zeta}\right], \tag{9}$$

where $q(\theta(w, \mathbf{x}, \boldsymbol{\zeta}))$ is the probability that the firm meets a worker in submarket $(w, \mathbf{x})$ when the aggregate state equals $\boldsymbol{\zeta}$. For each submarket $(w, \mathbf{x})$, the free-entry condition

$$\chi(\mathbf{x}) \geq q(\theta(w, \mathbf{x}, \boldsymbol{\zeta}))\mathbb{E}\left[J(\mathbf{x}', \mathbf{y}_0, w, \boldsymbol{\zeta}') \mid h = 0, \mathbf{x}, \boldsymbol{\zeta}\right] \tag{10}$$

holds with complementary slackness, i.e. if $\theta(w, \mathbf{x}, \boldsymbol{\zeta})$ is non-zero, then the above condition must hold with equality.

Definition (Recursive Equilibrium)**.** *A recursive equilibrium consists of an aggregate state $\boldsymbol{\zeta}$, value functions for employed and unemployed workers, value functions for firms, search policy functions for workers, an hours policy function for firms, and a law of motion for the aggregate state such that (i) $\boldsymbol{\zeta}$*

evolves according to its law of motion, (ii) θ satisfies the free-entry condition, (iii) value functions for the workers and firms are satisfied, and (iv) the hours policy function solves (8).

The object ζ is very high dimensional. Therefore, computing the recursive equilibrium directly is computationally infeasible. However, our model admits a block recursive equilibrium.

Definition (Block Recursive Equilibrium)**.** *A block recursive equilibrium consists of a market tightness function θ, value functions for employed and unemployed workers, value functions for firms, search policy functions for workers, hours policy functions for firms such that (i) all functions only depend on ζ through z, (ii) θ satisfies the free-entry condition, (iii) value functions for the workers and firms are satisfied, and (iv) the hours policy function solves* (8).

A block recursive equilibrium is a recursive equilibrium in which all value functions and policy functions only depend on the aggregate state of the world, not the distributions of workers across firms.

Proposition (Existence, Uniqueness, Block Recursiveness)**.** *There exists a unique recursive equilibrium. This equilibrium is block recursive.*

The proof of this proposition closely follows Menzio et al. (2016). Existence and uniqueness follow from backward induction. We can compute the worker's and firm's value and policy functions in the terminal period using (6), (7), and (8). For each of these three equations, there exists a unique solution. Whenever the worker or the firm are indifferent between different values for hours worked, h, we break this indifference by choosing the outcome with the largest value of h.[29] With the value and policy functions for the terminal period in hand, we can compute the market tightness of submarkets that target workers of age $A-1$ using (10). Again, existence and uniqueness are guaranteed. With the market tightness in hand, we compute the value function for a worker age $A-1$ using (2) and (3). As a byproduct, this step also yields workers' search policy functions. Similarly, we can compute the firm's value function using (4). Again, to each of these equations, there exists a unique solution. Iterating backwards establishes the existence and uniqueness result for all $a = A, A-1, \ldots, 1$.

The fact that the resulting equilibrium is block-recursive can also be shown by backward induction. Take a worker age A — regardless of whether this worker is employed or unemployed — her value functions do not depend on the aggregate state of the economy. The same holds for a firm that employs a worker age A. Next, consider a worker age $A-1$. This worker needs to decide in which submarket to search for a job. The market tightness of each submarket is pinned down by the free-entry condition (9). The firm's expected value from posting the vacancy only depends on aggregate productivity z and the market tightness θ,

[29] For instance, if the firm is indifferent between employing a worker or laying the worker off, this assumption implies that the firm keeps the worker employed.

not the entire vector $\boldsymbol{\zeta}$. Therefore, the market tightness θ can only be a function of z. Consequently, the workers value and policy functions are only functions of z not the entire vector $\boldsymbol{\zeta}$. Iterating backwards establishes the result for all $a = A, A-1, \ldots, 1$. This result is important, because it permits us to compute the equilibrium of the model without having to keep track of the evolution of the entire vector $\boldsymbol{\zeta}$. Therefore, despite featuring aggregate dynamics and rich amounts of worker-level heterogeneity, the model is very tractable and its equilibrium can be computed quickly.

4.3 Implications

We assumed that the firm chooses working hours (8) unilaterally. The main reason for a firm to reduce a worker's hours is when the cost of employing the worker exceeds the benefits from doing so. The firm will not necessarily reduce the hours all the way to zero for two reasons. First, the firm needs to ensure that the worker's participation constraint is satisfied, i.e. that the worker receives at least as high a value from employment as from unemployment. Second, there are dynamic considerations that may prevent the firm from cutting hours all the way to zero. These involve the potential loss of human capital as well as increasing the likelihood that the worker will switch to a different firm while working reduced hours.

In Figure 6, we show the worker's value from working h hours in an environment with and without short-time compensation. The dashed line shows the worker's outside option. Short-time compensation pushes the value function upward for all values $h < 1$. In the graph, a worker would not be willing to work half her regular hours, $h = 0.5$, without short-time compensation. This worker would rather be unemployed. With short-time compensation, the worker would be willing to work half her regular hours, because the additional compensation, pushes her value function above the outside option.

In Figure 7, we decompose the firm's value function from employing a worker into the firm's flow profits and continuation values as a function of the magnitude of the productivity shock and hours worked. In the left panel, we show the flow value from employing a worker at h hours as a function of the magnitude of the productivity shock, y_m. Since we assumed that firm's output is a linear function in hours, when hourly output is larger than the hourly wage, the firm maximizes its flow profits by setting h to as large a number as possible. When hourly output is less than the hourly wage, the firm maximizes flow profits by setting h to as small a number as possible. When hourly output is less than the hourly wage, the firm maximizes flow profits by setting h to as small a number as possible. Therefore, the firm's flow profits rotate around the point where hourly output equals the hourly wage. If the firm only cared about flow profits, workers would either be laid off and work zero hours or workers would work full-time. There would be no interior solution. However, the firm also cares about its continuation value with the worker. The continuation value is shown in the middle panel of Figure 7. The continuation value is an increasing function in the magnitude of productivity (strictly increasing when productivity is persistent with $y_p > 0$) and working more hours shifts the continuation value upwards. The upward shift happens for two reasons: First, human capital accumulation is faster when a worker works more hours. Second, a worker who works more hours is less efficient at search and therefore less likely to switch to a different firm. The right panel of Figure 7 shows the firm's value function from employing a worker — i.e. the sum of the left and the middle panel. In the example, there are some realizations of y_m, for which the firm is only willing to employ the worker at reduced hours. The role of short-time compensation is then to ensure that the worker is willing to work reduced hours as illustrated in Figure 6.

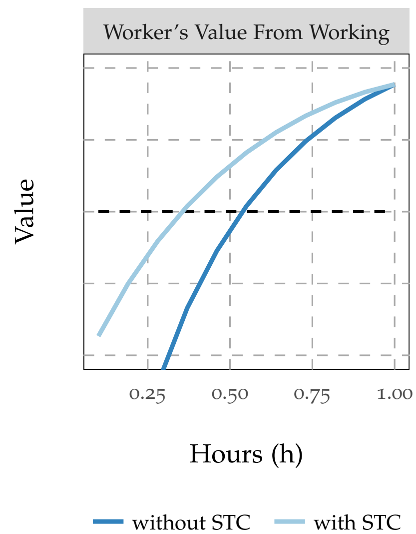


Figure 6: Worker's Value from Working

Note: The graph shows the worker's value from working h hours in an environment with short-time compensation and in an environment without. Short-time compensation pushes the value function upward for all values $h < 1$.

What makes reducing working hours attractive from the perspective of the firm? One of the key factors that make short-time work an attractive option for firms and workers is that productivity shocks differ in expected durations. In Figure 8, we illustrate how the firm's employment policy function depends on the magnitude and persistence of the productivity shock. The left panel refers to an environment without short-time compensation — i.e. firms can reduce their workers' hours, but this is not subsidized — and the right panel refers to an environment with short-time compensation. The magnitude of productivity shocks is plotted along the x-axis, the persistence along the y-axis. Realizations of y_m and y_p in the top-left corners of both panels are objectively bad. Productivity is low and persistent. Realizations of y_m and y_p in the top-right corners are objectively good, because productivity is high and persistent. Realizations of productivity in the bottom-left corner are low in magnitude and transitory; realizations in the bottom-right corner are high in magnitude and transitory.

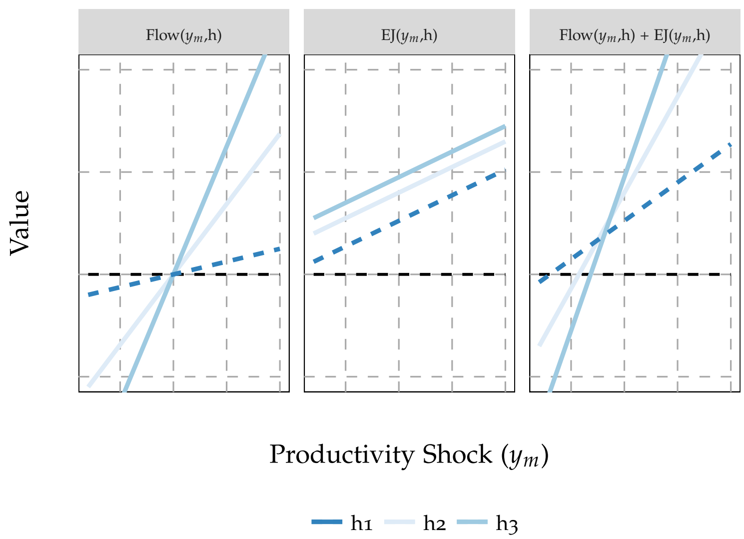


Figure 7: Firm's Choice of Hours

Note: The graphs show the firm's flow value, the firm's expected value in the subsequent period, and the sum of the two as a function of today's magnitude of the productivity shock from employing a worker at different levels of working hours h_1, h_2, and h_3. When hourly output is larger than the hourly wage, the firm maximizes flow profits by setting h to as large a number as possible. When hourly output is less than the hourly wage, the firm maximizes flow profits by setting h to as small a number as possible. But hours also have dynamic implications as they affect the evolution of human capital and the likelihood that the worker and firm will not separate. The firm's expected value of being matched with this worker in the subsequent period is increasing in the hours worked today. Combining both flows and expected values, the graph on the right-hand side shows that there may be realizations of y_m for which the firm is willing to continue only if it is possible for the firm to reduce working hours. The firm's ability to reduce a worker's hours depends on the amount of short-time compensation the worker receives.

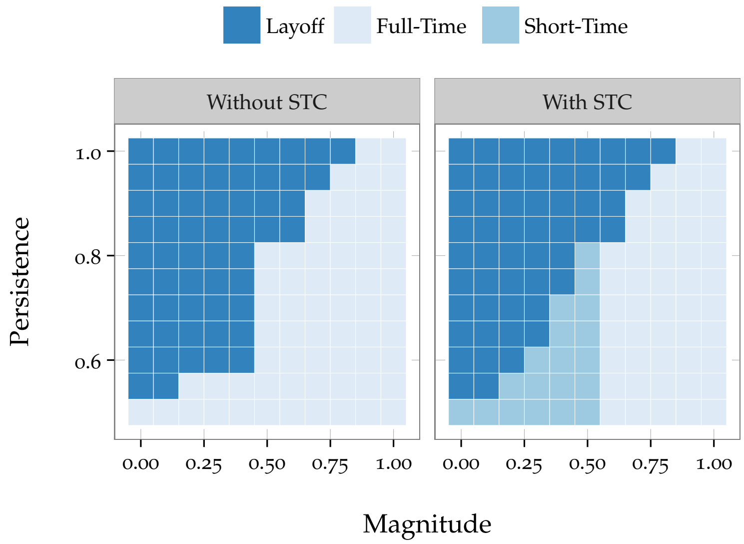


Figure 8: Firm's Policy Function as a Function of y_m and y_p

Note: The graphs show the firm's policy function — which includes full-time, short-time, or a layoff — as a function of the magnitude y_m and persistence y_p of the productivity shock. The graph on the left shows the firm's policy function in a policy environment without short-time compensation (i.e. the generosity of benefits equals zero). The graph on the right shows the firm's policy in a policy environment with short-time compensation.

The graph shows how the firm's policy function varies in the magnitude and persistence of productivity. For realizations in the top-left corner, workers are laid off with and without short-time compensation. For realizations in the top-right corner, workers work full-time with and without short-time compensation. For realizations that are relatively transitory, short-time work is used when reduced hours are subsidized. For a given level of persistence, firms are more likely to use short-time work, when the magnitude of productivity declines. Comparing the two panels illustrates the effect of short-time compensation on employment. Some short-time workers would have been laid off without short-time compensation, while some short-time workers would have worked full-time without short-time compensation.

In addition, the take-up of short-time work depends on the following: (i) the expected productivity of the worker after the short-time spell, which depends on the worker's current levels of general and specific human capital and the speed at which the worker accumulates or loses human capital while working reduced hours; (ii) the likelihood that a worker switches firms while working reduced hours. This likelihood is affected by the job finding probability of the worker, which in turn depends on the worker's general human capital and the worker's age; (iii) the age of the worker, which affects the duration of potential employment after the short-time spell.

We summarize the main trade-offs in the model in Figure 9.

Full-Time Work	Short-Time Work	Unemployment
produce output	some benefits/output	receive benefits
human capital ↑	human capital ∼	human capital ↓
keep contact ∼	keep contact ∼	keep contact ↓
leisure ↓	leisure ∼	leisure ↑
time to search ↓	time to search ∼	time to search ↑

Figure 9: Main Trade-offs in the Model

Note: The above illustrates the main trade-offs associated with full-time employment, short-time work, and (temporary) unemployment.

5 Estimation

5.1 Parametric Assumptions

A period in the model corresponds to one month. We choose a discount factor of $0.95^{\frac{1}{12}}$ that corresponds to a 5% annual interest rate. We assume that preferences are given by

$$u(c,h) = \frac{c^{1-\gamma_c}}{1-\gamma_c} - v(h),$$

where $v(\cdot)$ is a strictly increasing function. We fix the coefficient of relative risk aversion at $\gamma_c = 2$. We specify the production function as

$$f(\mathbf{x},\mathbf{y}) \times h = x_g y_s y_m h.$$

This production function nests a host of different assumptions. First, the production function states that general and firm-specific human capital are complements in production. Second, the production function is linear in hours. There is conflicting evidence on whether output is a concave or convex function of an individual worker's hours.[30] We choose the middle ground. Third, we assume that the different types of human capital and that the magnitude of match-specific productivity y_m enter the production function multiplicatively.

The aggregate productivity state of the world is a two-state Markov process with $\underline{z}$ corresponding to recessions and $\overline{z}$ to times of normal economic activity. The transition probabilities are estimated using recessionary periods in German GDP data. The probability of entering a recession is estimated to be 0.0156, which corresponds to an average duration between recessions of approximately 5 years. The probability of moving from a recession into normal times is estimated to be 0.1125, which corresponds to an average duration of recessions of about 9 months.

[30] For different findings on the nexus between productivity and hours worked, see for instance Feldstein (1967), Craine (1973), Leslie and Wise (1980), Shapiro (1986), Hart and McGregor (1988), Anxo and Bigsten (1989), Hanna et al. (2005), Bourlès and Cette (2007), Goldin (2014), Garnero et al. (2014), Lee and Lim (2014), and Pencavel (2015).

The magnitude of match productivity y_m is drawn from a normal distribution that depends on the aggregate state. We denote the location and scale parameter of this distribution by $\mu_{y_m|z}$ and $\sigma_{y_m|z}$ for $z \in \{\underline{z}, \overline{z}\}$. We discretize $\mathcal{Y}_m$ into 51 equidistant points on the interval $[0, 1]$. We introduce persistence into the match productivity shocks by having worker-firm matches draw a new match productivity shock with probability $y_p(z)$. With probability $1 - y_p(z)$, match productivity remains the same. We estimate the two parameters $y_p(\underline{z})$ and $y_p(\overline{z})$.

We model workers' general human capital x_g and firm-specific human capital y_s as ladders, each with 5 rungs on the interval $[1, 2]$. We estimate a curvature parameter for both ladders that governs the extent to which lower rungs are further apart than upper rungs. We assume that the initial value of x_g at birth corresponds to the lowest rung of the general human capital grid. The initial value of firm-specific human capital is assumed to be equal to the lowest rung of the specific human capital grid. While employed, workers climb up one rung on the general- and firm-specific human capital ladders with probabilities $\hat{\pi}_{x_g}$ and $\hat{\pi}_{y_s}$, respectively. They stay at their current levels with probabilities $1 - \hat{\pi}_{x_g}$ and $1 - \hat{\pi}_{y_s}$. While unemployed, workers fall down one rung on the general human capital ladders with probability $\check{\pi}_{x_g}$. Workers stay at their current levels with probability $1 - \check{\pi}_{x_g}$.

Working hours can take on five possible values $\{0.2, 0.4, 0.6, 0.8, 1.0\}$, where 1.0 corresponds to full-time employment. We parameterize the disutility from labor as a piece-wise linear function on the grid above. We allow the vacancy costs to vary in the worker's general human capital. We estimate a piece-wise linear function of the vacancy costs to reduce the number of model parameters. We directly estimate the parameter for exogenous separations $\delta(0)$ and assume that $\delta(h) = 0$ for $h > 0$. We also directly estimate the parameter for the search efficiency for employed workers, $\lambda(h)$. We assume that $\lambda(0) = 1$, and estimate $\lambda(h)$ directly, where we assume that $\lambda(h)$ is equal to constant for $h > 0$.

We parameterize the matching function as

$$p(\theta) = \frac{\theta}{(1 + \theta^{\omega})^{\frac{1}{\omega}}},$$

where ω is a parameter that we estimate. The probability that a firm meets a worker is therefore given by

$$q(\theta) = \frac{1}{(1 + \theta^{\omega})^{\frac{1}{\omega}}}.$$

Thus far, we have imposed no restrictions on the wage contracts that firms post other than that contracts are functions of x_g and y_s only. To solve the model, we need to impose some parametric restrictions on the wage contracts that firms post. We restrict all wage contracts to be linear piece rates in general human capital x_g and firm-specific human capital y_s, where firms are free to choose the piece rate.

As we outlined in Section 2, there were several policy changes to short-time work in early

2009. We do not want to model each of these changes separately. Since we already see some take-up in the data before the expansion (see Figure 2), we simplify matters by making short-time compensation available beginning in October 2008. We model the availability of short-time work in October 2008 as a surprise, but assume that short-time work will be available in all recessions afterwards. We set the generosity of short-time compensation to 60% and the payroll tax relief to 50%. We do not limit the duration of short-time work, as this will not turn out to be a binding constraint.

For the government policy functions b and τ, we use the following parameterizations. For the benefit function, we use a 60% replacement rate for both unemployment insurance benefits and short-time compensation. Short-time compensation is only paid when the aggregate productivity state of the economy is $\underline{z}$. The resulting benefit function is given by

$$b(r,h,z) = \begin{cases} 0.60 \times r & \text{if } h = 0 \text{ (unemployment)} \\ 0.60 \times r \times (1-h) & \text{if } 0 < h < 1 \text{ and } z = \underline{z} \text{ (short-time)} \\ 0 & \text{if } 0 < h < 1 \text{ and } z = \overline{z} \\ 0 & \text{if } h = 1. \end{cases} \tag{11}$$

When hours equal zero, i.e. when the worker is temporarily laid off, tax obligations equal zero. Under short-time work, the firm has to pay a 40% payroll tax on the actual compensation of the worker and a 20% payroll tax on hours not worked. Without short-time work, the firm has to pay a 40% payroll tax on the worker's full-time salary regardless of actual hours worked. The resulting tax function is given by

$$\tau(r,h,z) = \begin{cases} 0 & \text{if } h = 0 \text{ (unemployment)} \\ 0.40 \times h \times r + 0.20 \times (1-h) \times r & \text{if } 0 < h < 1 \text{ and } z = \underline{z} \text{ (tax relief)} \\ 0.40 \times r & \text{if } 0 < h < 1 \text{ and } z = \overline{z} \text{ (no relief)} \\ 0.40 \times r & \text{if } h = 1. \end{cases} \tag{12}$$

5.2 Simulation, Identification, and Estimation

We estimate the model using indirect inference. For a given vector of model parameters, we simulate data from the model and fit the same set of auxiliary models to both the simulated and the real data. We then search for the vector of model parameters that minimizes the distance between the estimates from the auxiliary models from the simulated and the real data.

For the estimation of the model, we restrict our data to men between the ages of 26 and 59. By focusing on men, we can abstract from labor force participation decisions. The age restriction permits us to abstract from schooling and retirement decisions. We further exclude observations that belong to individuals who have not worked a full-time job in the previous 24 months, because we consider these individuals as being out of the labor force.

We simulate data from the model by taking the realization of the aggregate state of the economy as given. We then start the economy in 1960 and forward simulate employment biographies. Workers who retire are immediately replaced by young workers. In our simulated dataset, we replicate some of the idiosyncrasies of our real data. We cap earnings at the social security threshold and we classify 15% of short-time workers as full-time employed to replicate the extent of misclassification in the real data.

The model has too many latent structures to provide a constructive identification argument of the various primitives. Instead, we will provide heuristic identification arguments for the various model features.

To separately identify the accumulation and depreciation processes for general and specific human capital, we rely on an identification argument similar to that in Flinn et al. (2017). General and firm-specific human capital have similar implications for wage growth but opposite implications for job-to-job transitions. A worker who is rich in general human capital and poor in firm-specific human capital is more likely to switch jobs than a worker who is rich in specific but poor in general human capital. Therefore, we target both wage growth and transition rates as a function of age, experience, and tenure. Among the transition rates we consider transitions from full-time work to unemployment and from full-time work to short-time work. To pin down the extent of general human capital loss during unemployment spells, we include as an auxiliary model, mean re-employment wages as a function of the duration of the unemployment spell. In addition, we use a set of standard Mincer regressions as an auxiliary model to ensure that the model-generated wage process is consistent with the basic life-cycle properties of earnings.

The duration of short-time work is informative about the persistence of match productivity during recessions. We use transitions from full-time work into short-time work at the onset of the recession to pin down the persistence of match productivity during times of normal economic activity. The distributions of the magnitude of match productivity can only be inferred indirectly, because we do not observe data on firms' profits. The initial level of match productivity for new hires critically affects how many vacancies firms post during good and bad times, which in turn affects the job finding probabilities. We therefore target the job finding rates by year and by experience, tenure, and age. Also, the distribution of match productivity for ongoing matches is critical for the firm's decision to lay workers off. We therefore target job to unemployment transitions by year and by experience, tenure, and age.

The remaining set of parameters includes the relative efficiency of on-the-job search, the elasticity of the matching function, and the vacancy posting costs. To identify these parameters, we add one additional data source on the number of vacancies posted. These data are collected by the Federal Employment Agency and are available at a monthly frequency. We match the average ratio of unemployed workers to vacancies posted. We then jointly pin down these parameters by targeting the transition rates from unemployment into full-time employment by worker's experience, and age, as well as job-to-job transitions by worker's experience, tenure, and age. We pin down the exogenous job destruction rate $\delta(0)$ by targeting the recall rate. We capture the disutility of work by targeting the distribution of hours worked by short-time workers.

We denote the vector of model parameters by Θ. We collect all of the model-simulated moments into the vector $\hat{G}(\Theta)$ and the data moments into the vector G. We then minimize the objective function

$$[\hat{G}(\Theta) - G]' W [\hat{G}(\Theta) - G],$$

where W is a diagonal weight matrix. As weights, we use the inverse of the variance of the data moments. For each evaluation of the objective function, we simulate $M = 30$ samples, each with the labor market histories of $50,000$ individuals.

The objective function is non-smooth, because in our simulated data, a finite number of individuals make discrete choices. We therefore slightly modify the model to smooth some of the discrete decisions that firms and workers make in the model. We then optimize the objective function using the commercial optimizer MIDACO (Schlueter et al., 2009), which is a general-purpose ant colony optimization algorithm that is well equipped to handle non-smooth problems and can easily be parallelized.

We obtain standard errors following Gourieroux et al. (1993). The asymptotic variance of Θ is given by

$$\frac{1+M}{M} \left[\frac{\partial \hat{G}(\Theta)}{\partial \Theta}' W \frac{\partial \hat{G}(\Theta)}{\partial \Theta} \right]^{-1},$$

where $\frac{\partial \hat{G}(\Theta)}{\partial \Theta}$ is a matrix containing the derivatives of each of the model moments with respect to each of the model parameters. The challenge in computing the derivatives of the simulated data moments is that these are not smooth functions in the parameter vector. We compute the derivatives of our simulated data moments with respect to the estimated parameter values by approximating the simulated moments with a cubic spline. We then compute the derivative of the spline evaluated at our estimated parameter values.

5.3 Estimated Parameters and Model Fit

We report the estimated parameters and their standard errors in Table 4. Some of the model parameters can be easily interpreted and we will discuss them now in turn. The persistence of productivity shocks in recessions is estimated at 0.67. The point estimate implies that during recessions, workers draw a new productivity shock approximately every four months, which is roughly in line with the average duration of a short-time spell of approximately four months. During normal economic times, the point estimate of persistence is 0.975, which

	Estimates	Standard Errors
Persistence of shocks: Low	0.671	0.004
Persistence of shocks: High	0.975	0.002
Accumulate y_s	0.019	0.003
Curvature y_s	0.744	0.007
Depreciate x_g	0.110	0.013
Accumulate x_g	0.017	0.002
Curvature x_g	0.548	0.002
Mean y_m for $z = \underline{z}$	1.122	0.003
Std Dev y_m for $z = \underline{z}$	0.585	0.022
Mean y_m for $z = \overline{z}$	1.315	0.003
Std Dev y_m for $z = \overline{z}$	0.041	0.001
Share of low persistence shocks when $z = \underline{z}$	0.976	0.004
Disutility v_1	0.546	0.006
Disutility v_2	0.559	0.008
Disutility v_3	0.867	0.004
Vacancy cost χ_1	0.259	0.017
Vacancy cost χ_2	0.284	0.016
Vacancy cost χ_3	0.572	0.016
Vacancy cost χ_4	1.580	0.019
Matching function elasticity ω	0.371	0.002
Exogenous separations $\delta(0)$	0.469	0.003
Relative efficiency of on-the-job search	0.346	0.004
Initial mean y_m for $z = \underline{z}$	1.466	0.004
Initial mean y_m for $z = \overline{z}$	1.373	0.003

Table 4: Model Estimates

Note: The model parameters are estimated using indirect inference. Standard errors are computed as in Gourieroux et al. (1993), which accounts for the additional noise resulting from the simulation.

implies that workers draw new productivity shocks approximately every three years.

The estimated parameters that govern the accumulation and depreciation of human capital indicate that specific human capital is accumulated at about the same rate as general human capital. Also, the curvature parameter for specific-human capital is greater than that for general human capital, rendering the returns to the former larger. During unemployment, general human capital is lost at about five times the rate at which it is accumulated during full-time employment.

The point estimate for the mean of the magnitude of match-specific productivity shocks is 1.12 during recessions and 1.32 during normal economic times. The associated variances are an order of magnitude larger in recessions than in normal economic times (0.59 vs. 0.04). The estimates of the disutility from working result in a function that is concave in hours worked. Posting vacancies targeting the lowest levels of general human capital is fairly cheap. It corresponds to 0.26 times an inexperienced worker's monthly salary. Posting vacancies targeted at worker's with the highest level of human capital is fairly expensive with a point estimate of 1.58 times an inexperienced worker's monthly salary. The probability that a worker who is temporarily laid off loses contact with her previous employer is 0.47. A laid off worker loses contact with her previous employer after an average of about two months. An employed full-time worker's search efficiency is 0.35 relative to 1.0 for unemployed workers.

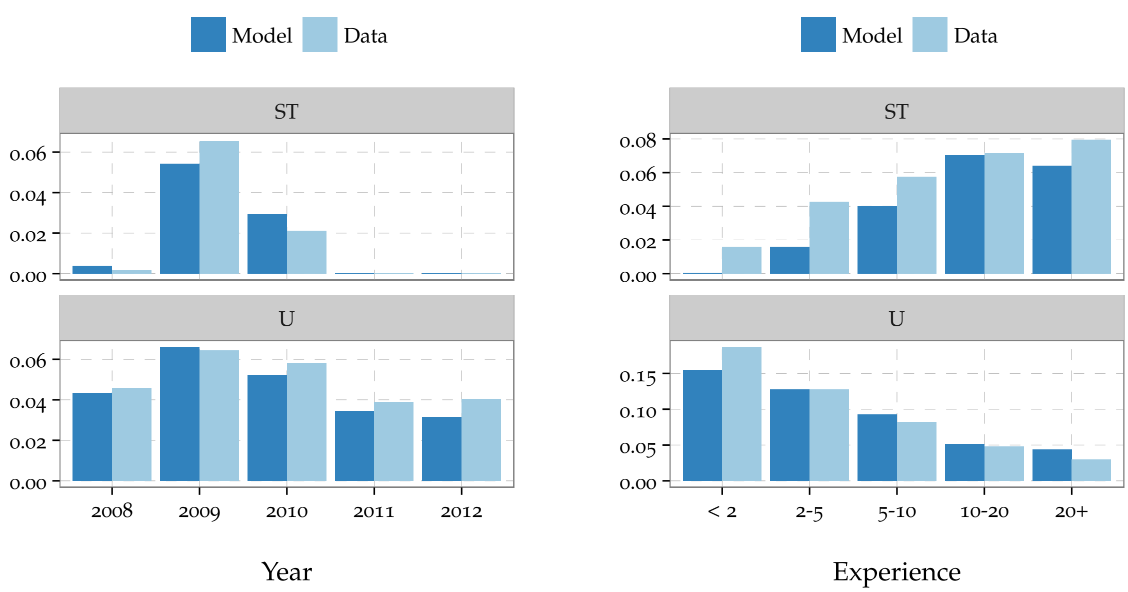


Figure 10: Model Fit — Employment

Note: The left graph compares the aggregate short-time and unemployment rates implied by the model to the actual rates observed in the data. The right graph does the same for the short-time and unemployment rates broken down by experience. The graph on the right refers to 2009 only.

Overall, the model fits the data well. In the left panel of Figure 10, we show that the model captures the aggregate evolution of the short-time rate and the unemployment rate well. The model captures both the exorbitant rise of short-time take-up in 2009 as well as its decline in 2009 and thereafter. The estimated model implies that workers do not work reduced hours during normal times when no government funded short-time compensation is available. The model also captures the modest increase in the unemployment rate during the recession and its subsequent decline. The right panel of Figure 10 shows that the model can also capture short-time and unemployment rates broken down by experience. The graphs shown refer to the year of 2009 only. In particular, the model captures that the short-time rate is steeply increasing in experience while the unemployment rate is steeply decreasing in experience.

We relegate all additional figures and tables that show the model fit to Appendix A2.

6 Results

In this section, we use our estimated model to investigate what effect short-time work has on employment and welfare. We compare outcomes in our estimated model to the counterfactual economy in which the generosity of short-time compensation equals zero and there is no payroll tax relief for firms that employ workers at reduced hours.

In the counterfactual economy, the benefits function equals

$$\tilde{b}(r,h,z) = \begin{cases} 0.60 \times r & \text{if } h = 0 \text{ (unemployment)} \\ 0 & \text{otherwise.} \end{cases}$$

and the tax function equals

$$\tilde{\tau}(r,h,z) = \begin{cases} 0 & \text{if } h = 0 \text{ (unemployment)} \\ 0.40 \times r & \text{otherwise.} \end{cases}$$

We use the following terminology. A worker who works reduced hours will be referred to as a short-time worker regardless of whether she receives compensation for the reduced income. We refer to the government transfer and the payroll tax relief collectively as short-time compensation.

Effects on Aggregate Employment

We first consider the aggregate impact on employment. In Figure 11, we plot the evolution of the short-time and unemployment rates with and without short-time compensation. Without short-time compensation, the unemployment rate in 2009 is 7.1% instead of 5.8%. This means that a short-time rate of 6.0% translates into a reduction of the unemployment rate of 1.3 percentage points. That means that one in five short-time workers would have been unemployed in 2009 without short-time compensation. The unemployment rate in 2010 is 6.3% instead of 5.5% and the unemployment rate in 2011 is 3.9% instead of 4.1%.

In Table 5, we show the evolution of job destruction, job finding, and recall rates. According to the model estimates, monthly job destruction rates in 2009 equal 0.015 without short-time compensation instead of 0.011 with short-time compensation. Average job finding rates modestly decrease with short-time compensation. Monthly job finding rates in 2009 are equal to 0.175 with short-time compensation instead of 0.177. Without short-time compensation, firms and workers may resort to more temporary layoffs, allowing the worker to temporarily receive unemployment insurance benefits and then be recalled. In Table 5, we report recall rates for both economies.[31] In 2009, the economy with short-time compensation has a considerably lower recall rate (5.3%) than the economy without short-time compensation (8.5%).

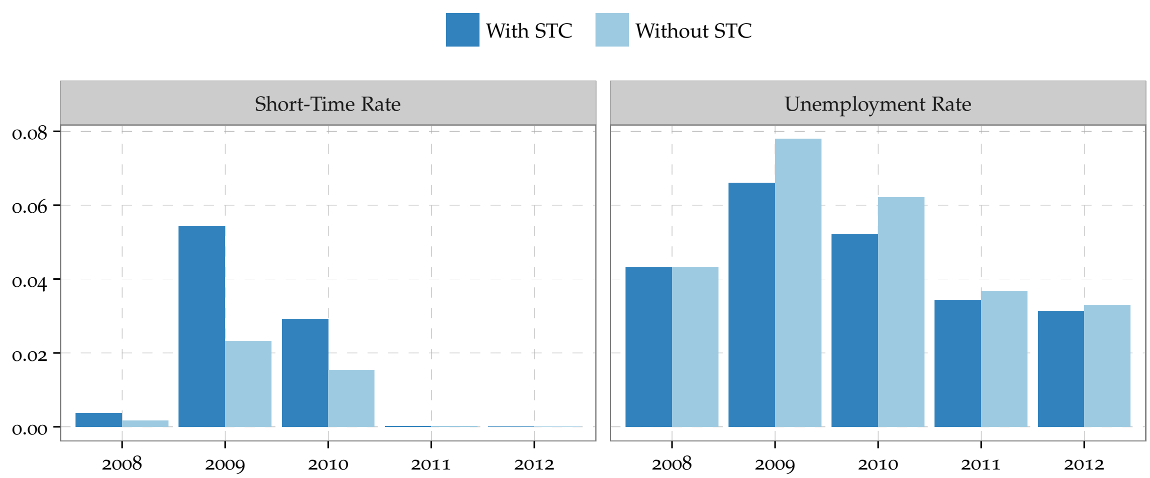


Figure 11: Counterfactual — Aggregate Employment

Note: The graph on the left shows the counterfactual short-time rate if short-time compensation had been equal to zero. Counterfactual short-time take-up refers to workers working reduced hours without any additional compensation. The graph on the right shows the evolution of the unemployment rate if short-time compensation had been equal to zero.

Our model permits us to break down the aggregate employment effect of short-time compensation by worker types. In Figure 12, we show the counterfactual employment state for each short-time worker in the data, broken down by experience and tenure. Proportionally, the number of jobs saved is largest for individuals with little experience and tenure. Among the group of most experienced workers, about 40% would have continued to work full-time with no reduction in hours. About 45% would have worked reduced hours without

[31] We define the recall rate as the ratio of the number of transitions from unemployment to full-time work where a worker returns to her previous employer over the total number of transitions from unemployment to full-time work.

	Job Destruction Rate		Job Finding Rate		Recall Rate	
	with STC	without STC	with STC	without STC	with STC	without STC
2008	0.012	0.012	0.175	0.178	0.132	0.139
2009	0.011	0.015	0.175	0.177	0.053	0.085
2010	0.007	0.008	0.175	0.172	0.098	0.111
2011	0.006	0.007	0.193	0.190	0.149	0.143
2012	0.006	0.006	0.199	0.196	0.175	0.176
2013	0.006	0.006	0.194	0.193	0.178	0.174
2014	0.006	0.006	0.202	0.198	0.175	0.172

Table 5: Counterfactual — Job Destruction Rates, Job Finding Rates, and Recall Rates

Note: The table shows the monthly job destruction, job finding, and recall rates as implied by the estimated model with short-time compensation and from the counterfactual model without short-time compensation. The recall rate is defined as the number of transitions when an unemployed worker returns to full-time work with her previous employer divided by the total number of transitions from unemployment to full-time employment.

compensation for foregone earnings. The remaining 15% would have been laid off. Even though short-time work is highest for more experienced and tenured workers, job savings are predominantly coming from workers with little experience and tenure.

Effects on Worker's Evolution of Employment and Earnings

Next, we consider the impact of short-time work on the future evolution of employment and earnings. Figure 13 shows the evolution of full-time employment for workers who initially transition into short-time work after at least six months of tenure in their current job. The graph shows the share of these workers in full-time employment as a function of time since the beginning of the short-time spell. Time is measured in months.

The left panel of Figure 13 shows the factual and counterfactual full-time employment paths for a worker who transitioned into short-time work at time zero in the estimated model, but would have remained in full-time employment in the counterfactual without short-time compensation. Short-time work does not have a lasting impact on the evolution of employment in the long-run. After approximately 10 months, the employment paths are identical. However, short-time work reduces full-time employment temporarily. The middle panel shows the counterfactual full-time employment path of a short-time worker who would have worked reduced hours in the counterfactual environment without short-time compensation. For this worker, the full-time employment paths hardly differ between the factual and counterfactual environments. The right panel shows the factual and counterfactual full-time employment paths for a short-time worker who would have been laid off without short-time compensation. These are the jobs that were truly saved by short-time compensation. Again, the full-time employment paths are remarkably similar. This means that workers who lose their job due to the absence of short-time compensation are workers who have relatively high job finding rates and will not be unemployed for very long. The reason that the job finding

Figure 12: Counterfactual — Employment of Short-Time Workers Without Short-Time Compensation by Experience and Tenure

Note: The graphs show what would have happened to short-time workers if the generosity of short-time compensation is equal to zero. The graph on the left breaks the counterfactual employment state down by short-time workers' experience, the graph on the right by short-time workers' tenure.

rates for these workers is high can be attributed to their age, experience, and the possibility of recall.

Figure 14 shows the evolution of earnings for workers who initially transition into short-time work after at least six months of tenure in their current job. The graph shows earnings as a function of time since the beginning of the short-time spell. The left panel of Figure 14 shows the factual and counterfactual earnings paths for a worker who transitioned into short-time work in the estimated model, but would have remained in full-time employment without short-time compensation. After approximately 10 months, the evolutions of earnings are identical. Short-time work reduces earnings temporarily, because it allows firms to reduce their workers' pay. The middle panel shows the factual and counterfactual earnings paths of a short-time worker who would have worked reduced hours at time zero in the counterfactual environment without short-time compensation. For this worker, the earnings paths hardly differ between the factual and counterfactual environments. The right panel shows the counterfactual earnings path for a short-time worker at time zero who would have been laid off without short-time compensation. For these workers, short-time compensation does in fact have a substantial effect on earnings that only disappears after about three years. Even though full-time employment recovers quickly for these workers (as shown in the right panel of Figure 13), earnings do not. However, this effect on earnings is not all that large compared to the extensive literature that finds that unemployment results in long-term earnings losses (e.g. Jacobson et al. (1993) or Davis and von Wachter (2011)).

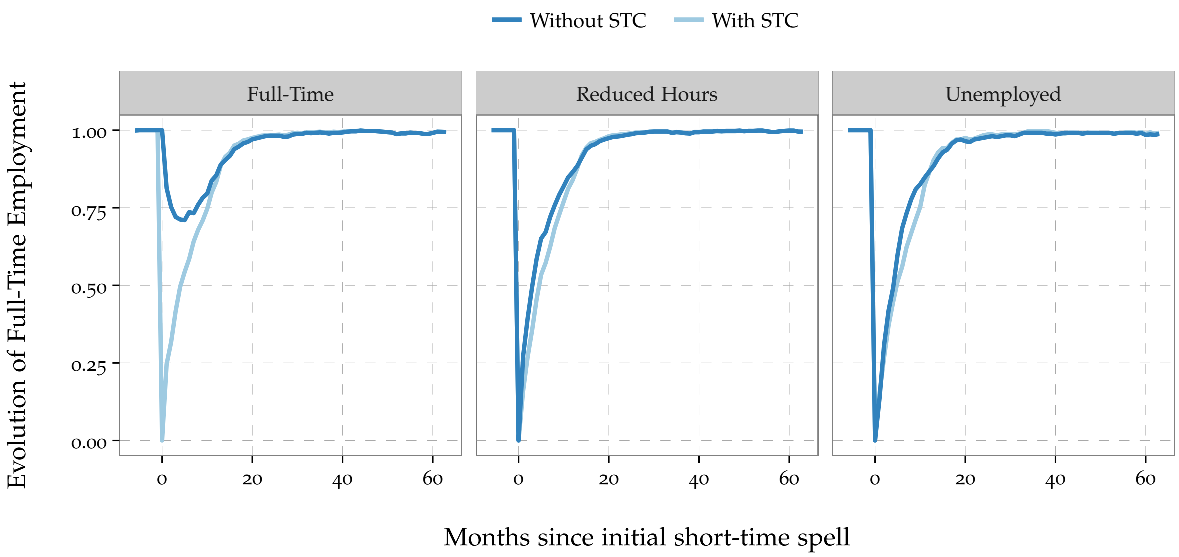


Figure 13: Counterfactual — Evolution of Employment of Short-Time Workers

Note: The graphs show the evolution of full-time employment of workers who initially transition into short-time work at time zero in the estimated model. The graphs are broken down by the counterfactual employment state of short-time workers.

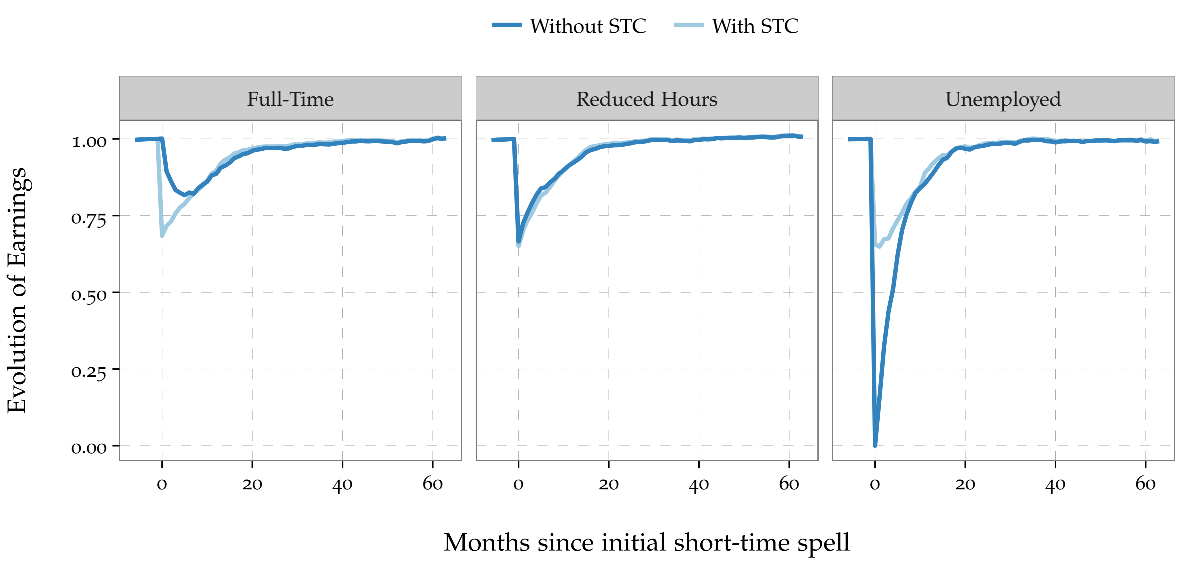


Figure 14: Counterfactual — Evolution of Earnings of Short-Time Workers

Note: The graphs show the evolution of earnings of workers who initially transition into short-time work at time zero in the estimated model. The graphs are broken down by the counterfactual employment state of short-time workers.

Welfare Effects

Next, we consider the effects of short-time work on workers' welfare, firms' profits, and the government budget. To measure the welfare effect, we simulate data from both the estimated model and the counterfactual economy without short-time compensation. We then compare each individual worker's flow utilities between the two environments and express the differences in terms of consumption equivalents. We take the sum of discounted consumption equivalents to quantify the impact on workers' welfare. To measure the effect on firm profits, we compute the sum of discounted firm flow profits under the two alternative environments. To measure the impact on the government budget, we compute the sum of discounted tax revenues minus government expenditures on unemployment insurance and short-time compensation. To measure the effect on output we compute the sum of discounted flow output minus spending on vacancy creation. Table 6 shows the results broken down by year. All quantities constitute annual averages per worker and are measured in Euros.

Workers benefit from short-time compensation throughout. In 2008, short-time compensation results in an average increase in worker welfare measured in consumption equivalents of EUR 22. In 2009, this figure rises to EUR 352, and drops in subsequent years. The government budget initially declines due to additional expenses for short-time compensation. The average cost of short-time work is EUR 141 per worker in 2009. In subsequent years, short-time work has a positive impact on the government budget, because workers are employed in better paying jobs and pay higher taxes. Firms' profits decline throughout due to short-time compensation. This can be attributed to the fact that short-time compensation affects workers' reservation wages, i.e. workers search for better paying jobs. Firms' spending on vacancy costs decreases substantially in 2009 and 2010. Overall, while short-time compensation results in a welfare loss per worker of EUR 105 in 2008, it results in a welfare gain of EUR 229 in 2009, and a welfare gain of EUR 445 in 2010.

	Δ Welfare	Δ Government	Δ Profits	Δ Vacancy Costs	Δ Total
2008	22	-39	0	89	-105
2009	352	-141	-55	-73	229
2010	256	69	-81	-201	445
2011	72	52	-25	-20	120
2012	36	32	-17	-1	53

Table 6: Welfare Results

Note: The table shows the effect of short-time compensation on workers' welfare, consumption, government expenditure, firms' profits, vacancy costs, and output. All quantities are measured in Euros. The average monthly salary in our data is about EUR 2,700.

7 Normative Implications

In this section, we ask what combination of unemployment insurance benefits and short-time compensation maximizes welfare and ought to be implemented by the government. We solve the government's problem, i.e. we maximize welfare subject to a government budget constraint.

Our model is non-stationary and does not admit a stationary distribution, which means we cannot simply cast the government's problem as maximizing steady state welfare. We choose the distribution of workers in January 2009 of the estimated model as the initial distribution for our optimal policy exercise. We cast the government's problem very narrowly. We ask if the German government could have made workers better off during and in the aftermath of the recession between 2008 and 2010 by changing the generosity of unemployment insurance benefits and short-time compensation *during* the recession. We keep government policy before and after the recession unchanged. In our model, workers cannot save. We do not want to overstate the government's role in helping workers borrow and save (through taxation in good times and tax breaks or subsidies in bad times). Therefore, we require the government to run a balanced budget during the recession. The government balances its budget by adjusting the payroll taxes accordingly.

The government chooses the generosity of short-time compensation, the generosity of unemployment insurance benefits and the payroll tax. We keep the payroll tax relief fixed at 50%. These policies only apply to the recession between 2009 and 2010. We denote the government's policy functions during the recession by b^* and τ^*. Before 2009 and after 2010, the government's policies are described by (11) and (12) and denoted by b and τ.

The government uses a utilitarian welfare function with equal weight on each worker. The per-period welfare function as a function of the aggregate state $\boldsymbol{\zeta}$ and the government's policy functions is given by

$$\mathcal{S}(\boldsymbol{\zeta}, b, \tau) = \underbrace{g_t^0(\mathbf{x}, r) u(b(r, 0, z), 0)}_{\text{Unmatched workers}} + \underbrace{g_t^1(\mathbf{x}, \mathbf{y}, w) u(w(\mathbf{x}, \mathbf{y}) h + b(w(\mathbf{x}, \mathbf{y}), h, z), h)}_{\text{Matched workers}}$$

The government's per-period budget is given by

$$\mathcal{B}(\boldsymbol{\zeta}, b, \tau) = \underbrace{g_t^0(\mathbf{x}, r) - b(r, 0, z)}_{\text{Unmatched workers}} + \underbrace{g_t^1(\mathbf{x}, \mathbf{y}, w)[\tau(w(\mathbf{x}, \mathbf{y}), h, z) - b(w(\mathbf{x}, \mathbf{y}), h, z)]}_{\text{Matched workers}}$$

The government solves

$$\max_{b^*, \tau^*} \underbrace{\sum_{t=t_0}^{t_0+23} \int \mathcal{S}(\boldsymbol{\zeta}, b^*, \tau^*) d\Lambda^*(\boldsymbol{\zeta}_t | \boldsymbol{\zeta}_{t-1}; b^*, \tau^*)}_{\text{During recession}} + \underbrace{\sum_{t=t_0+24}^{\infty} \int \mathcal{S}(\boldsymbol{\zeta}, b, \tau) d\Lambda(\boldsymbol{\zeta}_t | \boldsymbol{\zeta}_{t-1}; b, \tau)}_{\text{After recession}}$$

subject to

$$\sum_{t=t_0}^{t_0+23} \int \mathcal{B}(\boldsymbol{\zeta}, b^*, \tau^*) d\Lambda^*(\boldsymbol{\zeta}_t | \boldsymbol{\zeta}_{t-1}; b^*, \tau^*) \geq B_0.$$

where Λ^* is the transition function of the aggregate state during the recession for the actual realizations of z_t and t_0 refers to January 2009. We omit the arguments in the hours policy function to simplify the notation, but note that $h = h(x, w, y, \boldsymbol{\zeta})$. The government's budget is given by B_0, which corresponds to the government expenditure on short-time compensation and unemployment insurance benefits in the estimated model during the recession. We assume that the government can borrow and save at the interest rate $\frac{1}{\beta} - 1$.

We parameterize the benefit function b^* using two parameters b_1 and b_2 to denote the replacement rate of unemployment insurance benefits and short-time compensation, respectively.

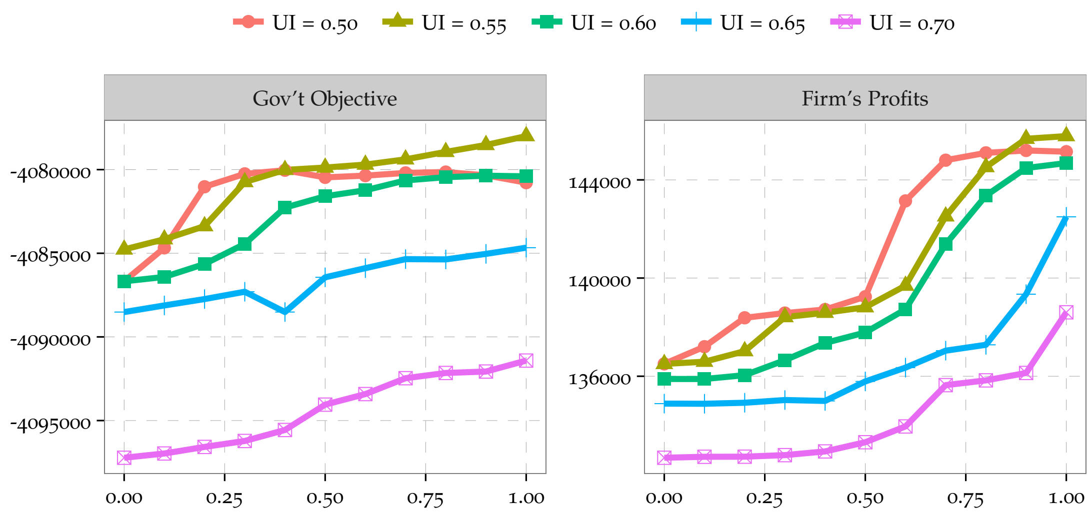
$$b^*(r, h, z) = \begin{cases} b_1 \times r & \text{if } h = 0 \text{ (unemployment)} \\ b_2 \times r \times (1-h) & \text{if } 0 < h < 1 \text{ and } z = \underline{z} \text{ (short-time)} \\ 0 & \text{if } 0 < h < 1 \text{ and } z = \overline{z} \\ 0 & \text{if } h = 1. \end{cases}$$

We parameterize the tax function using one parameter t_1 that refers to the payroll tax levied on prorated earnings.

$$\tau^*(r, h, z) = \begin{cases} 0 & \text{if } h = 0 \text{ (unemployment)} \\ t_1 \times h \times r + 0.5 t_1 \times (1-h) \times r & \text{if } 0 < h < 1 \text{ and } z = \underline{z} \text{ (tax relief)} \\ t_1 \times r & \text{if } 0 < h < 1 \text{ and } z = \overline{z} \text{ (no relief)} \\ t_1 \times r & \text{if } h = 1. \end{cases}$$

In the left panel of Figure 15, we show how the government's objective function varies with different choices for the replacement rates of short-time compensation and unemployment insurance. Average worker welfare is increasing in the replacement rate of short-time compensation and decreasing in the replacement rate of unemployment insurance benefits. Changes in the generosity of unemployment insurance benefits have a larger effect on welfare than changes in the generosity of short-time compensation. The optimal policy mix involves a replacement rate for unemployment insurance benefits of 0.55 (instead of 0.60, which we used in the estimation) and a replacement rate for short-time compensation of almost 1.0 (instead of 0.60). In the right panel we show firm profits. Firm profits are increasing in short-time compensation and decreasing in unemployment insurance benefits.

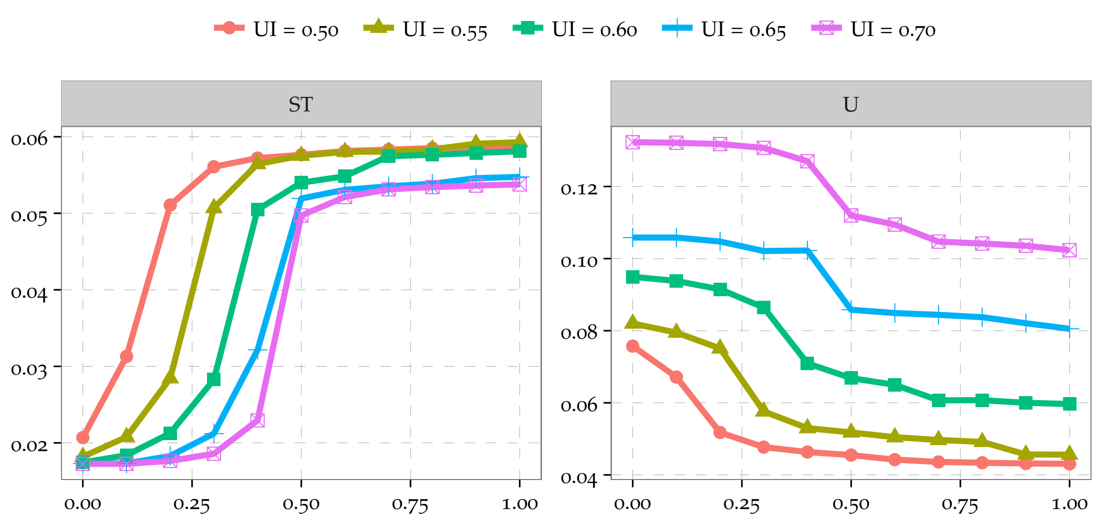
In Figure 16, we show how the replacement rates affect short-time take-up and unemployment. In the left panel, we show how short-time take-up varies in the replacement rates of



Replacement Rate of Short-Time Compensation

Figure 15: Optimal Policy — Workers' Welfare and Firms' Profits

Note: The graph on the left shows the government's objective function for different combinations of short-time compensation and unemployment insurance benefits. For each combination of short-time compensation, we compute the payroll tax rate that balances the government budget. The graph on the right shows average discounted firm profits.



Replacement Rate of Short-Time Compensation

Figure 16: Optimal Policy — Short-Time Work and Unemployment

Note: The graph on the left shows the short-time rate for different combinations of short-time compensation and unemployment insurance benefits. For each combination of short-time compensation, we compute the payroll tax rate that balances the government budget. The graph on the right shows the unemployment rate.

unemployment insurance and short-time compensation. Unsurprisingly, short-time take-up is increasing in short-time compensation and decreasing in unemployment insurance benefits. In the right panel, we show how the unemployment rate depends on the replacement rates. The unemployment rate is decreasing in the generosity of short-time compensation and increasing in the generosity of unemployment insurance benefits.

8 Direct Evidence

In Section 6, we presented the employment effects of short-time work based on our estimated model. In this section, we attempt to corroborate these findings with more direct empirical evidence.

We seek to answer the following question: How many jobs would have been destroyed if there had not been any short-time compensation? Answering this question is difficult: Selection into short-time work depends on employer and worker characteristics that are unobserved by the econometrician. Therefore, we cannot interpret the estimates that we reported in Figures 4 and 5 as causal. Short-time workers are likely to substantially differ from workers who are laid off even after controlling for all observable characteristics in our data. Researchers usually overcome these challenges using variation of labor market policies across space, e.g. by using a differences-in-differences approach as commonly done for studies on the U.S. labor market where different states implement different policies. In our case, short-time work is a federal policy, which implies that even if we had data on more than one geographic region, we could not exploit variation in the policy across space, because there is none. Also, short-time work is a policy that is only available during recessions. Therefore, we cannot use time variation to study the effects of short-time work on employment, because by construction the availability of short-time work is correlated with the aggregate state of the economy.

In the absence of variation across space, we will exploit variation across time and industry, by relying on the combination of two different sources of quasi-exogenous variation. The first source of variation is a policy change in the beginning of 2009, which we outlined in Section 2. The second source of variation is that the recession affected different industries at different points in time.

We estimate the effect of short-time compensation on job destruction rates by comparing industries that experienced their largest decline in output before January 2009 when short-time compensation was difficult to access to industries that experienced their largest decline in output after January 2009 when short-time work was widely available.

Our dataset does not permit us to measure output at the firm-level. We therefore measure output at the industry level. Here we use data from Germany's Federal Statistical Office, which produces monthly time series of industry-level output at the three-digit level. These data are only available for industries in the manufacturing sector, which we will focus on in this analysis. We classify an industry as entering a recession when the production index initially drops below its 12-month moving average by more than a standard deviation. According to this definition, 85% of workers in manufacturing in our data work in an industry where such an event happened between January 2008 and December 2009.

In Figure 17, we show the raw data of the production index for various industries that we classified as entering the recession before January 2009. In Figure 18, we show the raw data for various industries that we classified as entering the recession in or after January 2009. We then merge this information on when industries entered the recession with our worker-level data. For each employed worker we compute the time until and since the beginning of the recession for the current industry. We only include observations for workers in the manufacturing sector.

We focus on job destruction rates around the beginning of each industry-specific recession. We introduce two simple linear probability models for workers' transitions from full-time employment to unemployment and short-time work. Individual workers are indexed by i and calendar time by t. We denote the point in time when worker i's industry enters the industry-specific recession by $\tau(i)$. We denote the left-hand side variable by y_{it}, which refers to either a job destruction or a transition to short-time work. We focus on the initial response to the onset of the industry-specific recession by considering the first six months (we denote the offset by s for $s = 0, 1, \dots, 5$).

$$y_{it} = \sum_{s=0}^{5} \alpha \mathbf{1}\{\tau(i) + s = t\} D_i^{\text{before}} + \sum_{s=0}^{5} \beta \mathbf{1}\{\tau(i) + s = t\} D_i^{\text{after}} + X_{it}'\mu + \gamma_t + \varepsilon_{it},$$

The coefficients γ_t are calendar time dummies, D_i^{before} is a dummy that equals one if i experienced the recession before a particular cutoff date, and D_i^{after} is a dummy that equals one if i experienced the recession after the cutoff. X_{it} is a vector of worker-specific covariates. α and β are our coefficients of interest. α is the change in job destruction rates at time s for industry i with short-time compensation relative to all other industries at the same time. β is the change in job destruction rates at time $\tau(i) + s$ for industry i without short-time compensation relative to all other industries at the same time. We include monthly calendar time dummies to control for seasonal effects and aggregate developments. The data also include workers who work in industries that did not enter the recession.

We report the estimates for α and β in Table 7. We find that the average job-destruction rate is about a third of a percentage point higher for workers in industries that were affected by the recession before the cutoff than for workers in industries that were affected by the recession after the cutoff. As to be expected, transition rates to short-time work are zero for workers who were affected by the recession before the cutoff (when short-time was difficult to access) and are large for workers who were affected by the recession after the cutoff.

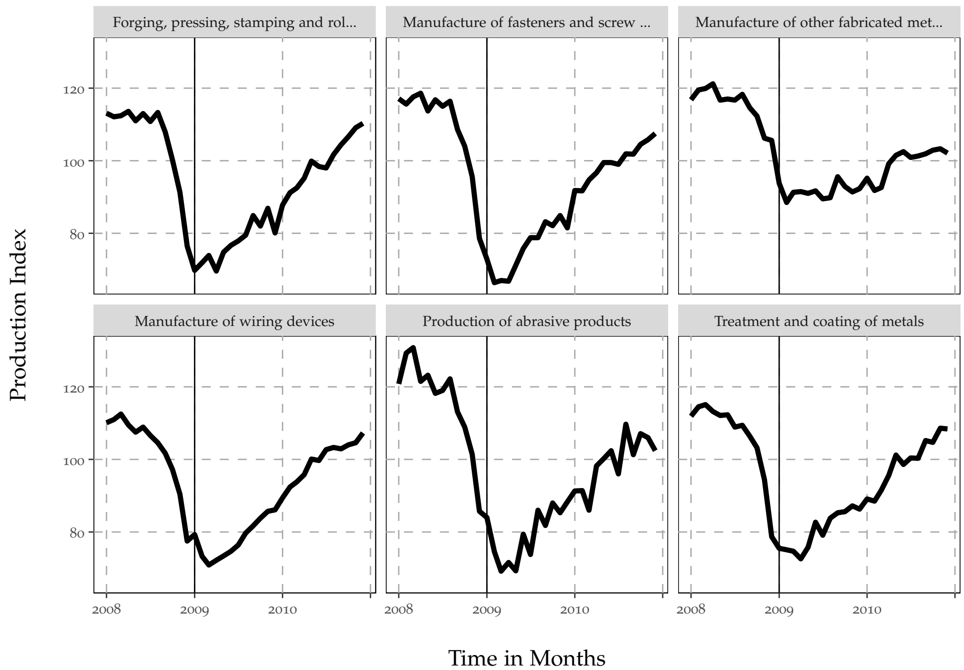


Figure 17: Recession Begins Before January 2009

Note: The graph shows the raw data for a selection of industries that are classified as entering the recession before January 2009.

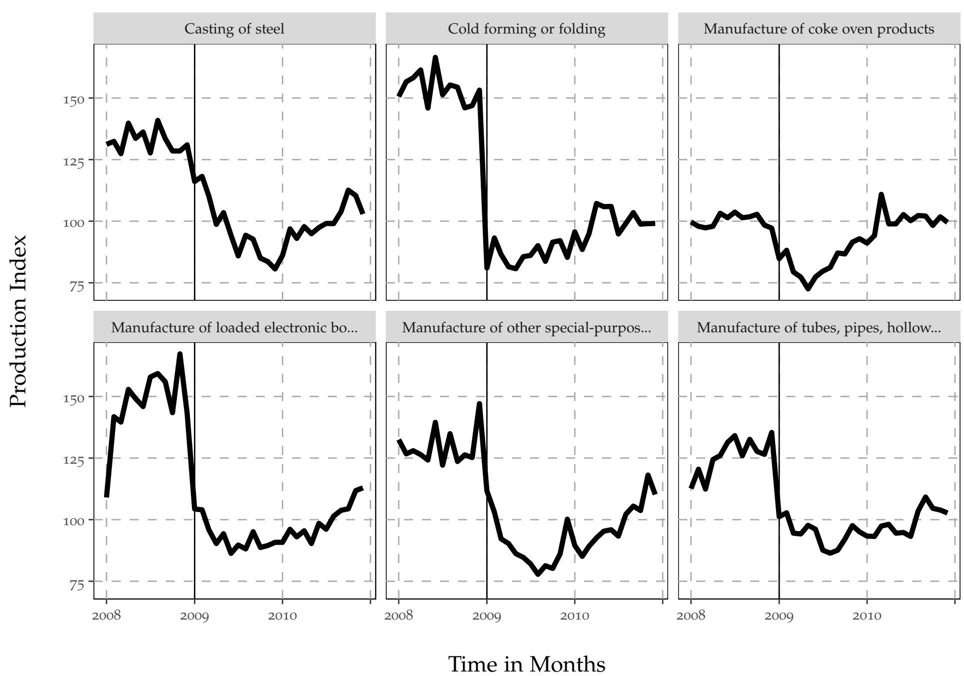


Figure 18: Recession Begins After January 2009

Note: The graph shows the raw data for a selection of industries that are classified as entering the recession in January 2009 or thereafter.

	Unemp.	Unemp.	Short-Time	Short-Time
Before	0.0018	0.0017	-0.0001	0.0001
	(0.0002)	(0.0003)	(0.0000)	(0.0000)
After	-0.0013	-0.0013	0.0108	0.0120
	(0.0002)	(0.0002)	(0.0005)	(0.0005)
Covariates	no	yes	no	yes
Calendar time dummies	yes	yes	yes	yes

Table 7: Coefficient Estimates for α and β

This is approximately in line with the impact short-time compensation has on the job destruction rates implied by our model, as reported in Table 5. In our model, short-time work decreases job destruction rates from 0.015 to 0.011, implying a difference of 0.004 — very close to the direct estimate of 0.003 that we obtain from the data.

9 Conclusion

We present a novel micro dataset of Germany's experience with short-time work during the recession between 2008 and 2010. The dataset shows that short-time take-up is increasing in work experience and tenure, short-time work is not associated with a long-run loss in earnings, and the vast majority of short-time workers return to work full-time at the same firm. We develop a model that is consistent with these facts. In the model, firms and workers face productivity shocks that differ in magnitude and duration. Short-time work is an instrument that allows firms to reduce working hours in response to a negative productivity shock instead of laying workers off.

The estimated model indicates that short-time work can considerably reduce unemployment during recessions. However, the welfare gains of the policy are small. This is not surprising. In the model — and in the real world — a worker who suffers a long-term earnings loss due to a layoff will not be laid off in response to a temporary productivity shock. Instead, this worker is willing to tolerate a considerable reduction in hours and earnings while staying employed, even in the absence of short-time compensation. The notion that short-time work prevents layoffs that would have devastating consequences on workers' careers is not supported by our theory.

In our analysis, we assume that for ongoing employment relationships, working hours are the only way for workers and firms to respond to productivity shocks. We argue that this is consistent with German labor market institutions and supported by the data. In particular, we do not observe that firms and workers renegotiate hours *and* wages during the recession. However, this assumption has major implications for the usefulness of short-time work. When employment contracts are fully flexible and permit permanent renegotiation of hours and wages, short-time work will have a considerably smaller impact on employment. Further empirical work that investigates the degree of contractual flexibility that firms and workers have during temporary downturns is important to evaluate the efficacy of programs such as short-time work.

Furthermore, we have omitted two important aspects of short-time work. First, we have not considered how short-time work interacts with other labor market institutions, such as firing restrictions, overtime rules, or working time accounts (i.e. mechanisms that allow firms to smooth working hours over time). Second, we have not considered how short-time work affects a firm's workforce as a whole. Our model is centered on one-worker firms, a necessity for tractability. However, it is conceivable that when a firm reduces its wage bill by reducing hours for some workers using short-time work, it enables the firm to keep other workers employed whom it would have otherwise fired.

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A1 Data Appendix

A1.1 Additional Figures and Tables of Data

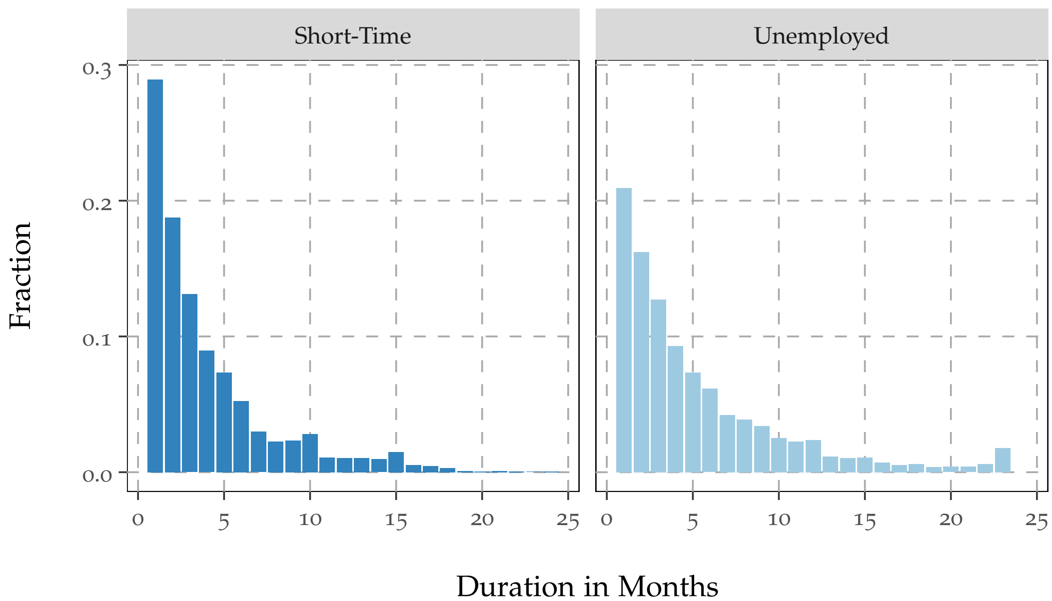

Figure A1: Distribution of Durations

Note: The histograms show the duration of short-time work and unemployment. The data cover all short-time work and unemployment spells that began between June 2008 and December 2012.

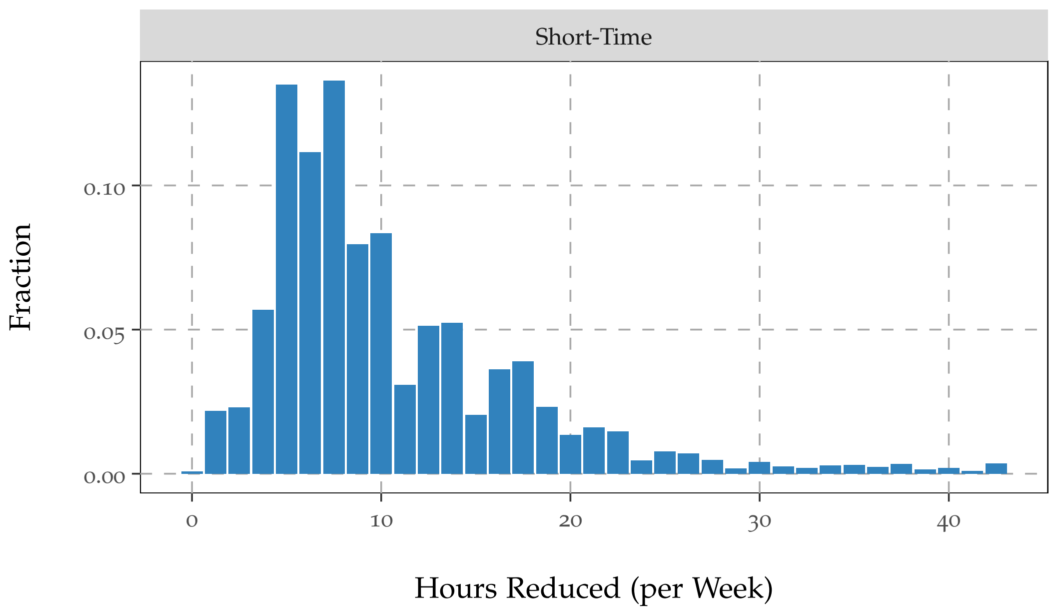

Figure A2: Distribution of Reduced Hours

Note: The histogram shows the number of reduced working hours (i.e. the number of hours for which short-time compensation was paid) per week.

A2 Model Appendix

A2.1 Distributions

We denote the aggregate state of our model by $\boldsymbol{\zeta} = \left[z, g^0(\mathbf{x}, r), g^1(\mathbf{x}, \mathbf{y}, w)\right]$, which consists of the aggregate productivity state z, the distribution of unmatched workers, $g^0 : \mathcal{X} \times \mathbb{R}_+ \mapsto [0, 1]$, and the distribution of matched workers, $g^1 : \mathcal{X} \times \mathcal{Y} \times \mathcal{W} \mapsto [0, 1]$. The distribution of unmatched workers keeps track of worker types $\mathbf{x}$ and their most recent full-time compensation r. The distribution of matched workers keeps track of worker types, $\mathbf{x}$, firm types, $\mathbf{y}$, and wage contracts, w. We denote the endogenous transition distribution function of the entire state $\boldsymbol{\zeta}$ by $\Lambda(\boldsymbol{\zeta}'|\boldsymbol{\zeta})$.

To solve our model, we do not construct the distribution function Λ explicitly. Instead, we rely on simulating individual workers' employment histories, which in aggregate evolve according to Λ. Here, we briefly outline which stochastic processes and worker flows characterize $\Lambda(\boldsymbol{\zeta}'|\boldsymbol{\zeta})$.

- The aggregate productivity state z follows a Markov process and evolves independently.
- The measure of unmatched workers, $g^0(\mathbf{x}, r)$, has the following inflows and outflows:
  - *Inflows:* Young workers who are born at age $x_a = 1$. Matched workers who are permanently separated from their employer with probability $\delta(h)$.
  - *Outflows:* Unmatched workers retiring at age $x_a = A$, unmatched workers who become matched with a firm.
- The measure of matched workers, $g^1(\mathbf{x}, \mathbf{y}, w)$ has the following inflows and outflows:
  - *Inflows:* Workers who were previously unmatched and become matched with a firm. Workers who were previously matched with a different firm.
  - *Outflows:* Matched workers retiring at age $x_a = A$. Workers who switch to a different firm. Workers who are permanently separated with probability $\delta(h)$.

A2.2 Computation

To compute the solution to the model numerically, we need to make several minor adjustments to guarantee that the numerical solution is smooth in the model's parameters. This is important to do both estimation and counterfactual analysis. Smoothness is not guaranteed because we discretize the state space and workers and firms make discrete choices. Therefore, an infinitesimal change of one of the model's parameters (or the government's policy) may result in large changes in the model's variables (e.g. the employment rate), because changing the parameter value moves a group of individuals in the model from one discrete state to the next. We therefore add idiosyncratic "choice errors" from a generalized extreme value distribution to the various discrete choices that workers and firms make.

A2.3 Estimation

Moments

We estimate the model using indirect inference. We target a total of 574 moments including

- Full-time employment, unemployment, short-time work shares over time by experience and age
- Quantiles of unconditional earnings distribution
- Quantiles of unconditional tenure/experience/age distribution
- Wage growth on-the-job by experience, tenure, age
- Wage growth off-the-job by experience and age
- Transition rates from full-time employment into unemployment over time by experience, tenure, and age
- Transition rates from full-time employment into short-time work over time by experience, tenure, and age
- Transition rates from full-time employment into employment at a different firm over time by experience, tenure, and age
- Transition rates from unemployment into full-time employment over time by experience and age
- Transition rates from short-time work into full-time employment over time by experience and age
- Recall rates for unemployed workers over time
- Coefficients from a Mincer earnings regression

A2.4 Additional Figures and Tables of Model Fit

	Model	Data
Recall Rate	0.13	0.14
Short-Time Duration (Months)	3.63	3.96
Short-Time Hours (Share of Full-Time)	0.34	0.27

Table A1: Model Fit — Duration, Hours, Recall

Note: The table shows the model fit of short-time duration, the fraction of hours reduced during short-time spells, and the recall rate. The recall rate is defined as the share of transitions from unemployment to full-time employment where a worker returns to the employer that immediately preceded the unemployment spell.

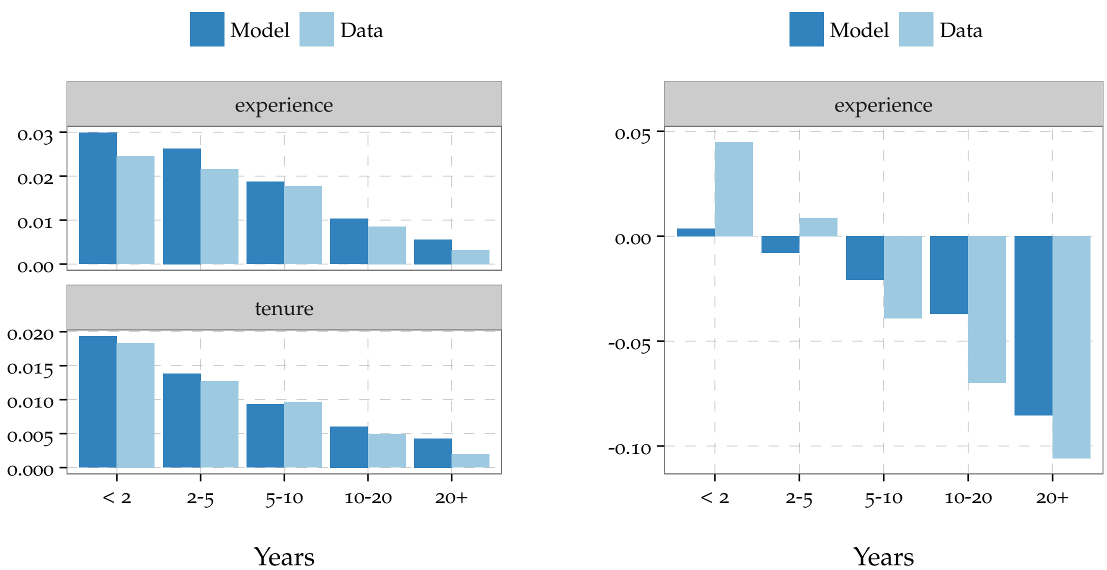

Figure A3: Model Fit — Wage Growth On- and Off-the-Job

Note: The graph on the left shows the model fit for the annualized wage growth on-the-job as a function of a worker's experience and tenure. The graph on the right shows the model fit for wage growth off-the-job between two jobs as a function of a worker's experience.

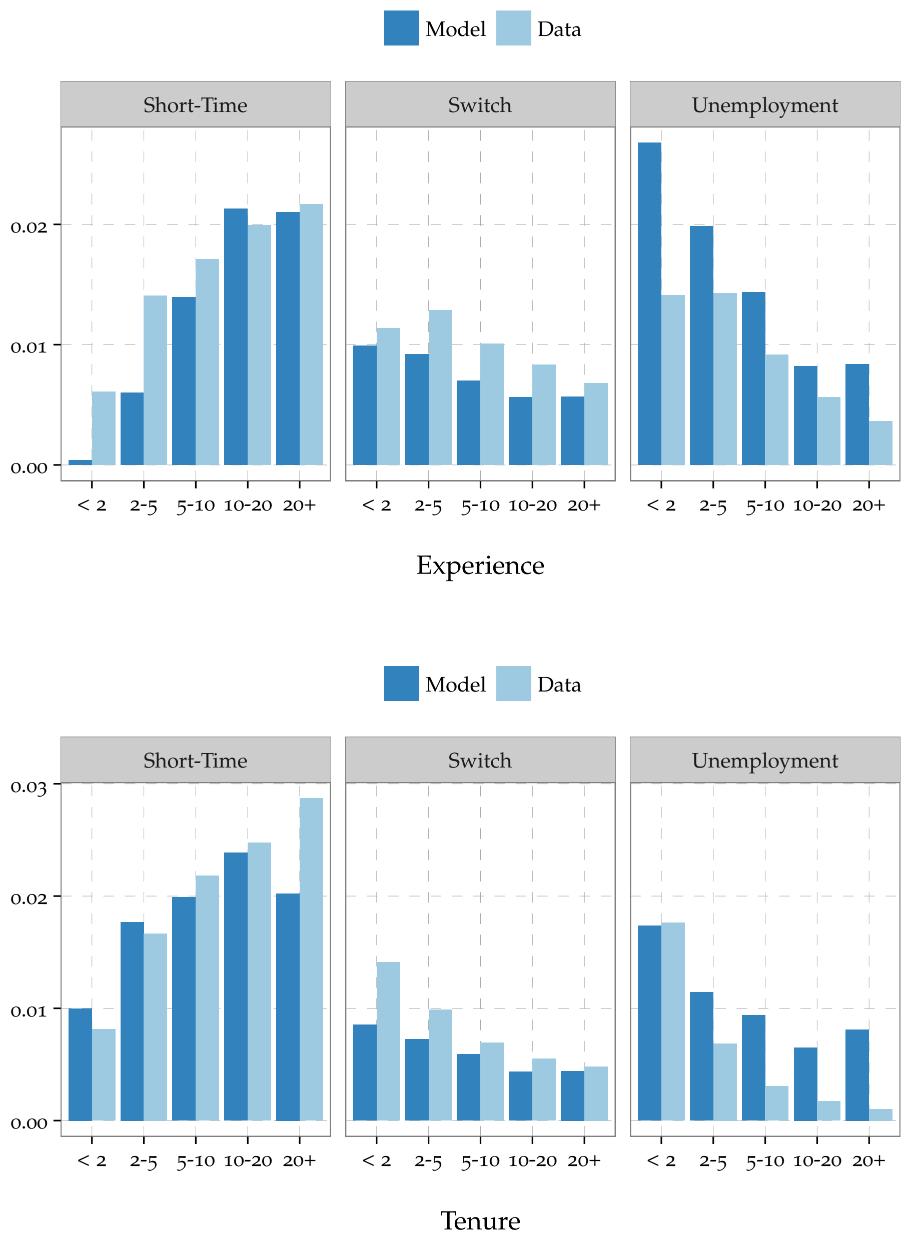

Figure A4: Model Fit — Transition Out of Full-Time Work

Note: The graphs show the model fit for the month-to-month transition rate from full-time employment into short-time work, full-time work with a different firm, and unemployment.

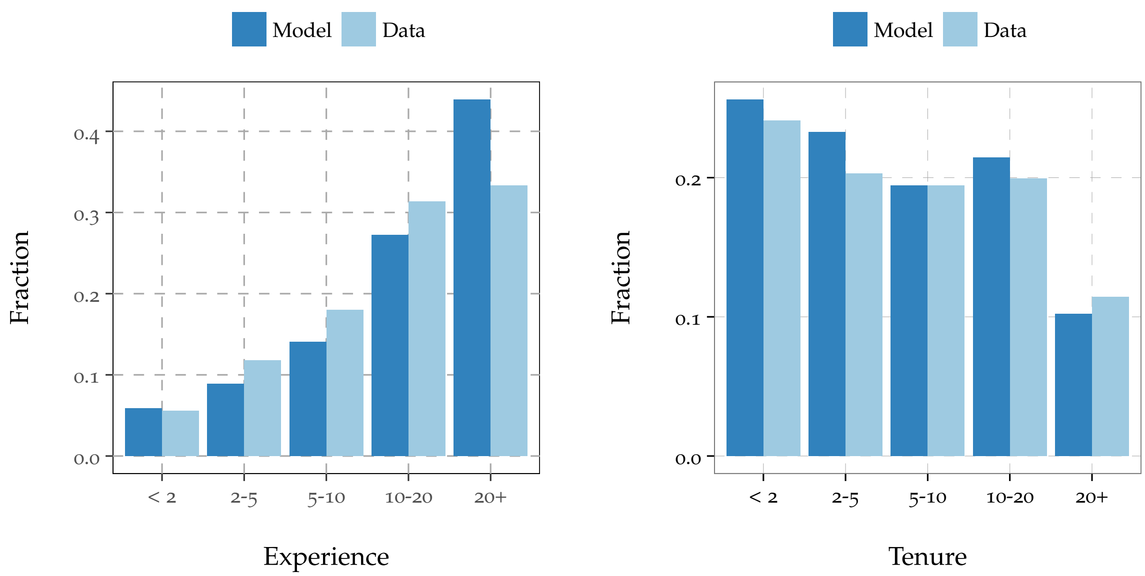

Figure A5: Model Fit — Unconditional Distributions

Note: The graph on the left shows the model fit for the unconditional experience distribution. The graph on the right shows the model fit for the unconditional tenure distribution.