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DISCUSSION PAPER SERIES

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ABSTRACT

The Welfare Costs of Job Loss and Decarbonization– Evidence from Germany's Coal Phase Out*

Decarbonizing economies is an enormous task. Public debate often focuses on the job loss of workers in fossil industries. Why is job loss costly? Who is most affected? Can delaying transition reduce welfare costs? What other policy instruments may be available? We present a simple job search framework that calculates life-time welfare costs of job loss. We apply the model to the archetypical fossil industry - coal mining. Based on the universe of German coal employment biographies, we estimate the model and decompose welfare costs. We find that unemployment is a small factor: Higher wages and job security in coal drive welfare costs. We distinguish welfare costs by age, education and business cycle. High-educated workers aged 31-49 face highest losses. Based on a detailed demographic projection, we estimate that advancing coal exit from 2038 to 2030 increases unmitigated welfare costs by one third. Labor market policy promoting career switches rather than retirement can alleviate these welfare costs: A wage insurance scheme is estimated to reduce welfare losses by 80-99% at reasonable costs.

JEL Classification: J64, L16, Q54

Keywords: job loss, structural change, just transition, coal exit

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1 Introduction

Technological change and climate policy are leading to major reductions in workforces in industries producing and relying on fossil fuels. The associated job loss is often considered a major negative consequence. The coal industry is a prime example for a steadily declining traditional industry that once provided high paying jobs, both in the US and in many European countries. However, the specific welfare costs are rarely quantified nor the precise contributions differentiated. Costs depend importantly on the quality and availability of alternative job opportunities, the age distribution of workers in the industry and the level of social welfare available to individuals. We present a stochastic labor market model for assessing welfare costs based on transitions across labor market states and suggest a labor market policy that compensates workers for welfare losses while encouraging labor market participation. The model includes the likelihood of retiring, job loss and associated industry moves, as well as associated income streams in current and alternative employment opportunities.

We apply our model to the German coal-mining industry. We use exhaustive administrative data on employment biographies to estimate labor market dynamics and associated income streams for different workers in the coal industry. We address four related questions:

First, why is job loss costly? Many commentators focus on the cost resulting from periods of unemployment. We decompose the total welfare costs of coal exit into its components: (i) income loss during a period of unemployment after job loss; (ii) (potentially) lower income in subsequent employment; and (iii) the associated level of job security of subsequent employment may be different from that in coal mining.

Second, who is most affected by job loss? We compare welfare costs of coal exit across different individuals. To do this we estimate our model separately for individuals according to age, education and macro-economic conditions.

Third, how do costs vary with the final closure of the industry, and how can these costs be reduced by labor policy? We simulate predicted employment and income dynamics under different scenarios of the end of the coal industry. In the German case, around 15,000 individuals in 2020 are employed in jobs that will be lost over the coming 10-20 years if coal-fired power plants are retired in line with climate objectives. We consider the implication for workers of different proposed exit dates.[1]

Fourth, how can public policy help? Various instruments have been suggested to soften the blow of industrial decline. While subsidized early retirement is a popular policy, we show that an alternative wage insurance scheme may greatly reduce welfare costs while maintaining employment.

We present several key findings: First, welfare costs per worker are considerable. Our baseline estimate is €155,283, equivalent to 5.8 times yearly earnings. These costs are almost entirely caused by lower job quality in alternative employment - lower job security and wages together account for $> 97\%$ of welfare costs, the role of unemployment pales in comparison. Second, workers aged 31-49 are most affected (around €337,000), contrasting with the main focus of state support for older workers. Third, total welfare costs across the industry decrease rapidly as a function of the timing of coal exit due to the demographic composition of the industry. A coal exit in 2030 in line with demand by the United Nations would generate around one third higher welfare costs to workers than the current German state policy of an exit in 2038 with total costs of around €1.45bn. However, total welfare costs for workers of an immediate coal exit (around €4.15bn) are limited compared to public spending on transition policies for workers a coal exit in 2038 (around €5bn). Fourth, a counterfactual policy simulation of a policy of subsidising workers who move to other industries can reduce welfare costs by over 90% for a coal exit 2030, at reasonable cost (around €615m).

[1] The government appointed a Coal Commission, a stakeholder body whose recommendation the government promised to follow. This body suggests a coal exit by 2038. However, this date is later than the recommendations of international bodies such as the OECD and the IMF, and was set before the recent increase in EU climate ambition.

We focus on a frequent focus of public attention: The welfare of workers in a declining industry, choosing a "people-based approach" compared to place-based analysis. As (Jacobsen et al., 2021) argue, migration in particular complicates any mapping of spatial outcomes into individuals' welfare. Prior studies focusing on individual worker outcomes rely on difference-in-differences frameworks to study the effect of environmental taxes (Yip (2018)), clean air regulations (Walker, 2013), or changes in the competitivness of different industries (Marchand, 2012; Curtis, 2018). In absence of a structural framework, these studies do not explicitly evaluate the welfare losses suffered by workers losing their job, and they do not perform counterfactual policy simulations. We explicitly formalize the underlying values of employment, unemployment and re-employment which allows us to estimate total welfare costs for different types of workers. Our aim is similar to Jacobson et al. (1993) and Couch and Placzek (2010) who contrast actual earnings after a labor demand shock with expected earnings over a number of years. We explicitly model the total discounted value of employment and costs of job loss by individual characteristics and macroeconomic conditions taking into account job security. Our model can be interpreted as a simplified version of the equilibrium models by (Burdett et al., 2020) who identify average costs of job loss across the whole economy.

Other strands of the literature have focused on labor market effects of industrial dynamics: One line of work considers the long-run aggregate equilibrium effects of increased industrial activity such as Bartik et al. (2019), Allcott and Keniston (2018), Jacobsen and Parker (2016), Michaels (2011), Black et al. (2005) and Hafstead and Williams III (2018). These studies focus on the local, regional and sectoral effects of rapid changes in labor demand, investigating in particular potential spillovers to other sectors and whether sectoral crowding-out creates a "resource curse". Our work is also complementary to research that exploits mass layoffs to identify labor market reactions (in a German context, see Schoenberg et al. (2019) and Schmieder et al. (2018)). Mass layoffs offers an interesting setting by reducing issues of selection, but may not predict outcomes of job losses for slower industrial declines that are frequent in European contexts. We focus on a slow decline but take into account local unemployment levels, such that we can distinguish unemployment experience in better and worse times. Finally, our study contributes to research on labor market policy. Several instruments have been proposed to reduce welfare costs of job loss. Early retirement has been a popular option (Batyra et al., 2019), mirroring how workers delay or anticipate retiring as a coping mechanism (Jacobsen et al., 2021). We instead focus on a wage subsidy that encourages job-to-job mobility while automatically benefiting those most affected by job loss. Others have noted the benefits of this policy in particular to counter trade-related job losses (Davidson and Matusz, 2006). In Germany, a similar scheme allowed older unemployed workers until 2011 (Van den Berg et al., 2017).

We focus on the coal mining industry. The coal industry is at the forefront of decarbonization. It is a large emiter of greenhouse gases and continues to play an important role as an energy source for electricity production (around 38.5% globally and 25% in Germany (IEA, 2018). Coal exit in OECD countries by 2030 appears necessary to achieve the 1.5° target of the Paris agreement (Parra et al., 2019), and the 2030 goal has been adopted by bodies including the UN and IMF. Second, the coal industry highlights the difficulty of industrial change. The coal industry contributed significantly to European economic growth in the past (Fernihough and O'Rourke, 2021) and is tied closely to industral dynamics in Germany (Gutberlet, 2014). Like the oil and gas industry in other parts of the world, the coal industry is politically very well connected and losses both to firms and workers are very salient. An important element in public policy debates concerns the welfare costs of workers. We inform these debates with an assessment of their size and possible remedies.

Our evidence is relevant for decarbonization challenges in other industries and countries. Like other large fossil fuel industries, the coal industry was able to distribute considerable natural resource rents and paid high wages, a pattern also evident for oil and gas industries (Abowd et al., 2012). Resource rents may also be used to foster political support for the industries and protect capital investments. The potential for policy capture has been widely analysed in developing countries as a form of resource curse (Van der Ploeg, 2011), in Germany the coal industry also "continues to be intertwined with regional political and economic structures, and industry associations, utilities and mining unions still exert considerable lobbying power." (Leipprand and Flachsland, 2018). In other fossil industries the same causes - resource rents, geographic concentration and political economy - are likely to give rise to the same labor market effects - significant wage premia, high job security and slow transitions. The oil industry in Norway and France or the gas industry in the Netherlands and Russia may be examples. Our framework can also be applied to fossil fuel industries in less regulated labor markets in North America or Australia. While differences in job security may play a smaller role in welfare costs, wage premia may play a larger role in absence of trade union wage compression and firing costs.

Historically, German coal mining included hard (black) coal and lignite (brown coal). Hard coal mining ended in 2018, the remaining coal mines are open-cast lignite mining. Lignite is used in nearby power plants to produce electricity, it is rarely transported given its poor energy-to-weight ratio. Very little lignite is exported or used for heating. The prospect of employment losses in this sector has been the key barrier to a rapid coal exit in Germany. A government commission to find a consensual solution for the reduction of lignite capacities proposed early retirement and job guarantees as labor market tools to reduce welfare costs to workers (BMWI, 2020). The remainder of this paper focuses on that part of the industry that is certain to end operations when coal-fired power is retired: The lignite mining industry, including mining services. We exclude associated power plants where thermal power generation can continue after a coal exit. An obvious substitute for coal is gas, both natural or from biomass. Even if workers in power generation do lose their job, the welfare costs for this group are lower than for the employees in coal mining and mining services, since their profiles are more likely to be technical and less strongly tied to coal than the mining activities.

2 Model

We seek to identify the monetary costs incurred by individuals who lose their coal job as a result of climate policies. We model these costs as the difference between two expected income streams: First, the expected value of continued coal-sector employment $V^C(.)$. This expected value takes into account the fact that individuals may be laid off or retire (often before the official retirement age). We also allow this value to vary across individuals with different characteristics. Second, workers' material welfare when unemployed, $B(.)$ - including benefits b, the likelihood of finding a new job or of retiring. To analyze these two objects, we set up a simple stochastic model of the labor market.

Unemployed individuals of type x find jobs at Poisson rate $\lambda^{NC}(x)$ in the non-coal sector and at rate $\lambda^C(x)$ in the coal sector. These jobs pay wages drawn from type-specific wage distributions $F^C(., x)$ and $F^{NC}(., x)$ respectively. Jobs end with exogenous probability $\delta(x)$ or when individuals retire at rate $\rho(x)$. We discount incomes at homogeneous discount rate r, ignoring additional costs related to risk aversion[2]. Our model precludes voluntary job moves, see section (2.4). In the empirical section, we censor any observed job-to-job transitions. Similarly, we assume that retirement decisions are involuntary and individuals retire with some probability $\rho(x)$, which will importantly depend on age, one of the components of the vector of individual characteristics x.

$$WFC(w, x) = V^C(w, x) - B_0(w, x) \tag{1}$$

The value of unemployment in the first period after a worker has lost their job, $B_0(.)$m depends on workers' type x and previous wages, as a result of unemployment benefits

[2]Since we find that job security is an important determinant of welfare losses of job loss, our assumption here is conservative.

providing income substitution.

$$r\ V^C(w,x) = w + \delta^C(x)\left[B_0(w,x) - V^C(w,x)\right] - \rho(x)\ V^C(w,x) \tag{2}$$

$$r\ V^{NC}(w,x) = w + \delta^{NC}(x)\ \left[B_0(w,x) - V^{NC}(w,x)\right] - \rho(x)\ V^{NC}(w,x) \tag{3}$$

$$\begin{aligned} r\ B_m(w,x) = b_m(w,x) &+ \lambda^{NC}(x)\ \int V^{NC}(w',x) - B_m(w,x)\ dF^{NC}(w') \\ &+ \lambda^C(x)\ \int V^C(w',x) - B_m(w,x)\ dF^C(w') + \frac{dB}{dt} \end{aligned} \tag{4}$$

As a result of the deterministic reductions in benefits over unemployment duration, the system is non-stationary, as the term $\frac{dB}{dt}$ indicates. The amount of benefits individuals receive falls over time - income-related unemployment benefits expire and individuals move to (lower) means-tested social assistance.

Job-finding rates depend heavily on macroeconomic conditions. We model this by including a dependency of $\lambda(.)$ on the unemployment rate. In calculating the value of the labor market statuses at any point in time, we assume that macroeconomic conditions do not vary.[3]

The value of being unemployed depends on two dynamic components: First, elapsed time in unemployment m; Second, macroeconomic conditions included in the vector x. For all periods after duration in unemployment M, benefits reach a stationary level and

[3] An alternative could be to assume that the difference between the unemployment rate and some long-term level which holds after 12 months (and thereafter) decreases over time. In this alternative scenario, in the long run, unemployment converges to a constant level such that the value of unemployment and employment in the long run are actually constant. This reduces the differences in value of jobs across macroeconomic conditions. We leave this extension to future work.

no longer evolve.

$$B_m(w,x) = \frac{b_m(w,x)}{1+r} + \frac{\lambda^{NC}}{1+r} \int V^{NC}(w',x)\ dF^{NC}(w') \\ + \frac{\lambda^{C}}{1+r} \int V^{C}(w',x)\ dF^{C}(w') + \frac{1-\lambda^{NC}-\lambda^{C}}{1+r} B_{m+1}(x) \tag{5}$$

...

$$B_M(x) = \frac{b_M(x)}{1+r} + \frac{\lambda^{NC}}{1+r} \int V^{NC}(w',x)\ dF^{NC}(w') \\ + \frac{\lambda^{C}}{1+r} \int V^{C}(w',x)\ dF^{C}(w') + \frac{1-\lambda^{NC}-\lambda^{C}}{1+r} B_{M}(x) \tag{6}$$

Note that contrary to prior periods, the final (and all following) periods no longer depend on previous earnings (w), as unemployment benefits fall to a uniform level of social assistance. In setting up the value of unemployment in the final period, we are assuming that the current job-finding rate λ_M will prevail in future periods.

For the stationary value (at M) we can therefore rewrite (6) as follows:

$$\left[r + \lambda^{NC} + \lambda^{C}\right]\ B_M(x) = b_M + \lambda^{NC}(x) \int V^{NC}(w',x) dF^{NC}(w') \\ + \lambda^{C} \int V^{C}(w',x) dF^{C}(w') \tag{7}$$

$$B_M(x) = \frac{b_M}{r+\lambda^{NC}+\lambda^{C}} + \frac{\lambda^{NC}}{r+\lambda^{NC}+\lambda^{C}} \int V^{NC}(w',x) dF^{NC}(w') \\ + \frac{\lambda^{C}}{r+\lambda^{NC}+\lambda^{C}} \int V^{C}(w',x) dF^{C}(w') \tag{8}$$

To calculate this value, it helps to simplify the above as follows

$$B_M(x) = \frac{b_M}{r+\lambda^{NC}+\lambda^{C}} + \frac{\lambda^{NC}(x)}{r+\lambda^{NC}+\lambda^{C}} \left(V_M^{NC}(\underline{w}) + \frac{1}{r+\rho+\delta^{NC}} \int \overline{F}^{NC}(w') dw' \right) \\ + \frac{\lambda^{C}(x)}{r+\lambda^{NC}+\lambda^{C}} \left(V_M^{C}(\underline{w}) + \frac{1}{r+\rho+\delta^{C}} \int \overline{F}^{C}(w') dw' \right) \tag{9}$$

where we use by integration by parts - see appendix (A).

The value in employment may depend on macroeconomic conditions via the probabilities of becoming unemployed, $\delta(.)$, and of retiring $\rho(.)$ - and indirectly also via the probability of job-finding $\lambda(.)$. We thus have a set of simultaneous equations in $V^{NC}(w,x), V^{C}(w,x), B(x)$.

2.1 Solving the Model

First, consider the value of unemployment. The value of unemployment in the final period is stationary, as flow values (unemployment benefits) no longer evolve. The value of unemployment in the final period depends on the value functions V^{NC} and V^{C} (see expression (9)). For prior periods, we can back out the value for any pre-unemployment wage level using backward induction, as appendix (B) shows: For an employed worker falling into unemployment we can write unemployment benefits in the first period, B_0, as the sum of the value of long-run unemployment B_M and a type-specific constant K^b,

$$B_0(w,x) = B_M(x) + K^b(w,x), \tag{10}$$

where $K^b(w,x)$ depends on the previous wage w, the discount rate r, the transition parameters λ^C, λ^{NC} and the policy parameters $b_0, b_1, ..., b_M$. The precise expression for any duration in unemployment is given by (20). We apply the replacement rate of the unemployment benefit system (60%) to the pre-unemployment wage.

2.2 Algorithm

We implement the following algorithm to solve for the fixed point in our system of value functions.

1. Guess a vector of values $B_M(x)$. Recognizing the costs of unemployment and the relationship of the value of unemployment with later wage realizations, we initialize the system with a guess of the NPV of the infinite flow of one third of mean observed income by type x, i.e. $B_M^{initial}(x) = \frac{\bar{w}^{obs}(x)}{3\ r}$.

2. Based on $B_M(x)$ we determine the function $B_0(w,x)$ using (10) and thereby the functions $V^{NC}(w,x)$ and $V^{C}(w,x)$ using (2) and (3).

3. Conditional on these value functions, determine $B(.)$ using expression (9) - for every type x.
4. Update the vector of values $B_M(x)$ and move back to point (2).

The algorithm converges quickly in practice, after 4-5 runs.

2.3 Model stratification

We solve the model separately for labor markets differentiated by gender, age, education and macroeconomic conditions. Individuals assume that the labor market environment in which they are currently operating will not change. This is uncontroversial for gender and education which rarely change for adults, but we argue also acceptable for macroeconomic conditions and age. While macroeconomic conditions may vary, we focus on long-run economic conditions and using a cut-off value for local unemployment, reduce the dimensionality to two levels of macroeconomic conditions. While individuals may foresee changing conditions related to their age in the future, there is a large literature showing how limited this foresight is (Diamond and Köszegi, 2003), especially with respect to the most important factor in our model that evolves across our age classes, retirement (see lit on retirement choices, opt-in vs opt-out etc.). We take into account workforce aging when calculating changing total welfare losses of industrial decline in the future. To do this, we project the evolution of the age distribution of coal workers and simulate how many workers of type x we predict to remain in employment and their individual welfare costs.

Calculating the welfare cost of losing a job requires determining the values of the following parameters, as function of a vector x of individual characteristics and macroeconomic conditions: $\lambda^C(x), \lambda^{NC}(x), \delta^C(x), \delta^{NC}(x), \rho(.), \mu^C, \mu^{NC}, \sigma^C, \sigma^{NC}$. These parameters will also allow us to assess current and future welfare losses of different individuals.

2.4 Discussion

Our model relies on assumptions. The most fundamental assumption we are making concerns the determinants of labor market transitions. We assume that transitions depend only on the characteristics which we are controlling for (individual characteristics and macroeconomic condition) and are otherwise stochastic.

In particular, first, in the model we present, we do not include voluntary job-to-job movement. Where a worker quits the coal sector to move to another job we censor the spell. This appears an acceptable strategy given our research question and greatly reduces complexity[4]: If the distribution of welfare in the state following a job-to-job transitions is similar (in expectation) to the expected welfare consequence of remaining in a job, then we are not understating the value of jobs by not including job-to-job transitions. We think this is a fair assessment as some job-to-job transitions are actually involuntary job losses followed by jobs not necessarily of same quality. In fact, for only a minority of job-to-job transitions out of coal are associated with wage increases: In fact, 57% face a decrease in earnings upon moving job-to-job.

Second, when analyzing the costs of job loss in the coal sector, we assume that job opportunities in other industries are not affected by the coal exit. We are assuming that conditions remain the same outside of the coal industry. Future unemployment resembles past unemployment with the exception that workers may no longer find jobs in the coal sector. This appears conservative in the sense of not exaggerating the opportunities outside the coal sector.

A more optimistic vision may suggest that in the long run, jobs in the declining industry will be replaced by new jobs. In this case, job-finding rates in the future will not be lower than in the past. We test this alternative in appendiyx (E.1) and find only

[4] Binding reservation wages give rise to several complexities: In the fixed-point calculation of value functions each month in unemployment has a different value. More importantly, we can no longer estimate job offer arrival rate and wage-offer distribution independently of the value functions. Transition rates depend on reservation wages, these need to be called when estimating transition parameters. This comes at great numerical cost and needs to be implemented within tight constraints relating to our access to the administrative data. We therefore refrain from this.

small differences on estimated welfare costs as the coal industry represents only a small fraction of hires out of unemployment.

3 Empirical strategy

We assess the welfare consequences of job loss in the coal sector for different workers. To do this we first analyze labor market transitions based on our simple stochastic model of the labor market.

3.1 Data and Sample

We use comprehensive German social security records made available by the German Federal employment agency (BA) via the Institute for Employment Research (IAB). Our dataset, the Integrated Employment Biographies (IEB) includes employment and benefit recipient history. It comprises event history data on employees liable to social security, benefit recipients, job seekers, unemployed people and participants in measures of active labor market policies.

We extract the complete employment biography of the universe of all persons who worked in at least one coal sector establishment between 1st January 1975 and 31st December 2017 for a continuous period of at least six months. We include in our analysis not only employment in the coal sector defined as establishments that operate in either lignite mining or lignite mining services.[5] Importantly, we observe these individuals' outcomes before joining and after leaving the coal sector, including spells of unemployment. This allows us to analyze the labor market dynamics relevant for coal sector employees - in particural, the types of job offers ex coal workers can expect to receive.

[5] Whereas lignite mining is easily identifiable as a separate industry, the data do not distinguish between services for lignite mining and services for other mining activites (all included in economic activity 09.9, see Destatis (2008)). We include in this category firms operating in mining service if they are located in municipalities with lignite coal mining activities. Extensive tests considering geographic mobility and the location of other regional mining employers suggest that the vast majority of mining service employers in these municipalities are in the coal sector.

Table 1: Descriptive Statistics

	Estimation sample	**Coal job sample**
Spells	1,456,051	516,244
Distinct individuals	146,916	140,125
Age		
- 18-30 years	25.49%	31.38%
- 31-49 years	43.10%	35.75%
- 50+ years	31.41%	32.87%
Gender		
- Female	21.37%	19.57%
Education		
- Low-education	12.60%	22.19%
- High-education	85.60%	74.66%
- Missing	1.80%	3.15%
Location*		
- Lausitz	22.47%	28.37%
- Rhineland	15.00%	27.73%
- Central Germany	15.31%	16.02%
- Other Coal Regions	5.37%	7.71%
- Other Non-Coal Regions	41.85%	20.17%
Macroecon. condition		
- High-unemp	47.03%	59.86%
- Low-unemp	52.97%	40.14%
Labor market status		
- employed	84.39%	100%
- unemployed	15.61%	-

Notes: The estimation sample includes non-coal spells of workers who worked in the lignite coal industry for at least 6 months. These spells are used to estimate labor market opportunities for coal workers after leaving the coal industry.; *Regional classifications are provided in appendix (F).

We turn the process-generated spell data into economically meaningful job spells by linking records. We attribute an exclusive status by removing parallel spells (typically, secondary jobs, extra payments or social welfare payments). Table (1) presents our resulting sample of 1,456,051 spells from 146,916 distinct individuals. For these individuals we have information on personal characteristics (e.g. job/unemployment status, age, sex, qualification level), occupation, industry, firm establishment identifiers, wages, durations of unemployment and active labor market policies.

3.1.1 Coal worker sample

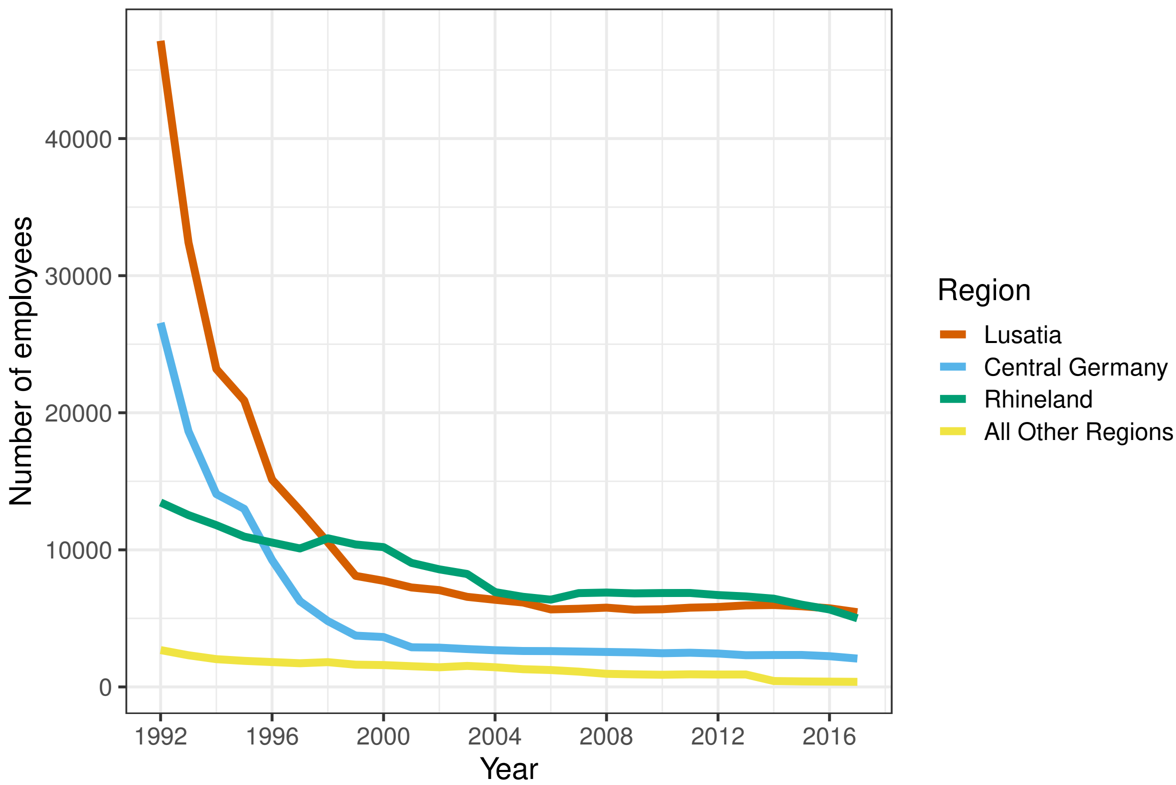
Our data includes 516,244 coal work spells - the remainder of spells concern employment and unemployment spells of workers that were employed in coal at other points in their career (table (1)). Over our sample observation period, there has been a trend decline in coal sector workforce, as others have documented (e.g. Brauers et al. (2018)). Figure (1) shows that the number of employees decreases from over 90,000 in 1992 to around 13,000 in 2017. This decrease in coal employment is driven by productivity growth. Despite the associated technological changes affecting the industry, the distribution of occupations has overall remained similar. Although there is some evidence of tertiarisation and automatisation (e.g. the fraction of vehicle drivers is declining), the changes appear small. Within the coal sector, the most frequent occupations are vehicle and other mechanics, management and office work, driving of vehicles, mechatronic engineering and mining & processing.

The decline of the coal industry is accompanied by workforce aging: We find that the average age increases from 38 years in 1992 to 46 years in 2017. This change in the age composition of the workforce informs our strategy of stratifying by age and including retirement probability as an outflow out of coal jobs.

The basic sample contains only 21.37% women. This limits the options for reliable inference by individual characteristics for this group. While the baseline results we present contain both women and men, the detailed analysis by individual characteristics presented in section (4.3) is only possible for men, as samples sizes were too small to estimate welfare losses for women with a high degree of confidence.

The distribution of geographic origins of our spells reflects the strong concentration of the mining sector. The concentration on three large mining areas is increasing over time.[6] In 1992, the two Eastern German mining regions account for most of our observations (53% from Lausitz and 30% from Central Germany), in 2017, 82% are located in either Lusatia (43%) or the Rhineland (39%) lignite mining regions, see figure (1).

Figure 1: Employees in lignite coal mining across mining areas



Macroeconomic conditions vary across the regions, with West German regions benefiting from lower unemployment rates. All regions benefit from a trend to lower unemployment levels over the sample period, leading to some convergence in levels. We categorize macroeconomic conditions into two categories, using a cut-off rate correspond-

[6]We have no reliable information on East German employment biographies prior to 1992 and thus focus on the evolution since 1992.

ing broadly to the average unemployment rate of the levels over our observation period. Regions with unemployment rates below ten percent are thereby classified as benefiting from good macro-economic conditions, regions with unemployment rates above ten percent as suffering bad macro-economic conditions.

3.1.2 Labor market status

Following our model, we categorize spells in two mutually exclusive labor market employment statuses: Normal employment (including both full-time and part-time employment) and unemployment. Spells end in transitions to another status, retirement or are censored. We drop parallel spells and second jobs.[7] We include in the category "Unemployment" also marginal employment (minijobs) and participation in active labor market programs and contrast these to regular employment. We do not include in estimation individuals in vocational training to whom our model of labor market dynamics fits less well. The proportion of vocational trainees is low in this sector, at around 3-5% throughout the observation period.

Retirement is explicit in the data for unemployed individuals and early retirement. For other workers, we impute old-age retirement as the last observation in the data for workers over 50 years of age.[8] Since we observe all employment, unemployment and social welfare spells, alternative reasons for the end of contribution history could involve: Joining the civil service (who have a different contribution scheme), becoming self-employed, moving abroad or having children. Most of these are unlikely to affect coal workers above the age of 50. We tested our strategy for imputing retirement on non-coal workers in our sample and found it to produce a credible distribution of retirement ages.

[7]Where information is inconsistent, we prioritize information from spells on unemployment benefits, vocational training, full-time employment and part-time employment in that order. Following standard practice, we also remove short gaps between two spells for which we lack information, as well as individuals whose employment biographies have a very large number of gaps. (We remove only 0.2% of observations based on the latter restriction.)

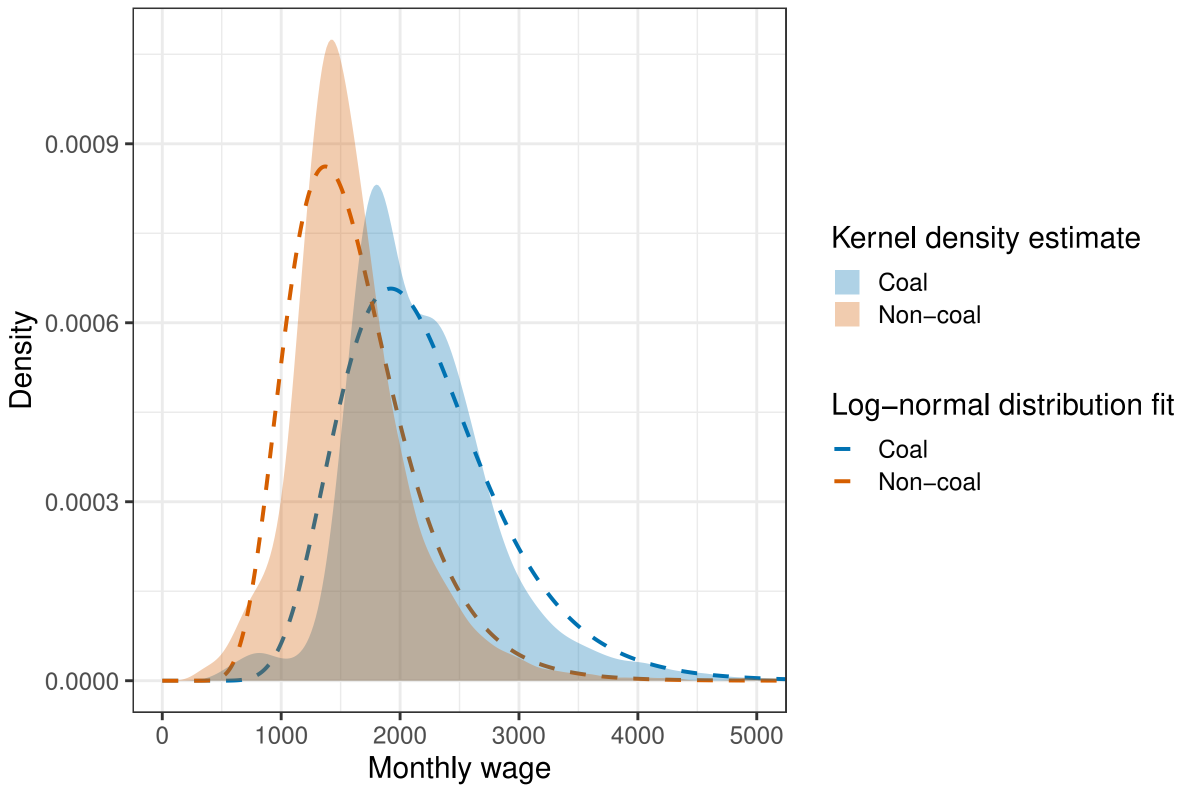
[8]We take into account that marginal employment (minijobs) may continue in retirement.

3.1.3 Earnings & Education

We have reliable administrative data on earnings for workers in both the coal and non-coal sectors. We deflate our nominal daily earnings data to monthly wages in 2010 prices using OECD information on consumer prices. Following Card et al. (2012), we deal with top-coding of earnings information by imputing above the assessment level. The resulting changes affect our results only very little. Details of the procedure are relegated to appendix (C).

Of particular interest for our research question is the last wage that coal workers receive before becoming unemployed and the starting wage after leaving unemployment. Figure (2) shows that coal-sector wages are on average considerably higher and that both distributions are fairly well approximated by a log-normal distribution.

Figure 2: Wages in coal (left) and starting wages in non-coal sector (right) & fitted lognormals



We have educational information from most individuals, though the quality of the administrative data is less good than for employment outcomes. We use the imputation technique outlined in Fitzenberger et al. (2006) to create a consistent indicator. We categorize formal educational outcomes into two groups: We classify as "low educated" those with neither a professional qualification, nor an apprenticeship, nor a certificate of higher education. The high-educated group consists mainly of individuals with an apprenticeship or another professional qualification (around 85%). The remaining smaller proportion of the high-educated group have qualifications from institutions of higher education.

3.1.4 Social welfare payments

Our social security records do not include precise information on unemployment benefits or social welfare payments. We therefore impute these, focusing on the three most important components and the changing levels over time and space: Unemployment benefits, social assistance and housing benefits. We base our assumptions surrounding unemployment benefits and social welfare on institutions that have remained fairly stable since the early 2000s. [9]

First, we assume that individuals receive 12 months of unemployment benefit with a replacement rate of 60%.[10] We thus generate monthly benefit payments $b_m(w_T)$ for $m \in \{1, 12\}$ from information on the last pre-unemployment wage w_T.

Second, for any further periods of unemployment $m > 12$, $b_m = b_M(.)$, we calculate social assistance payments according to the official rates valid in specific years. These means-tested payments are typically complemented by housing benefits. The value of housing benefits depends on individual housing arrangements. We use average per capita housing benefits paid in different German states.

[9]Our model would become intractable if we tried to allow for changing social welfare payments. The set-up we propose is driven by our desire to make predictions about future welfare losses.

[10]The assumption is correct for singles who have contributed to the unemployment insurance for 24+ months. The entitlement period is reduced for shorter tenures. Unemployed who care for children benefit from an augmented rate of 67%, but our data do not allow us to identify children.

3.2 Stratifying the sample

For the estimation of our parameters of interest, we stratify the sample, estimating the model parameters separately for different groups. We group men into 12 cells according to three criteria:

First, we distinguish three age groups: 18-30 year olds, 31-49, and 50 and over. Second, we separate individuals by their educational outcomes: A first group with no formal educational qualification contrasts to a second group with either a completed apprenticeship or other professional qualification, or a higher education qualification. Third, we distinguish between macroeconomic conditions, characterized by high or low levels of local unemployment. As a threshold for "high unemployment" we choose the level of 10% unemployment. To be able to distinguish by macroeconomic condition, spells that start in one macroeconomic environment but end in another are censored at the cut-off point, this affects 3.26% of spells. This is one reason why the sum of the cell samples does not equal to the total sample size reported in table (1)). The second reason is that we include women in the overall sample, but exclude them from this detailed analysis as a result of small sample sizes.

Appendix table (8) provides information on the sample sizes of the stratified estimation samples and number of transitions that are particularly relevant for identification.

3.3 Estimation of transition parameters

Given the postulated stochastic nature of job finding, job loss and retirement, durations in different labor market states identify the transition parameters in the coal and non-coal sectors. We have the following parameters to estimate: λ_{NC}, δ_C, δ_{NC}, ρ.

The transition parameters are estimated using maximum likelihood. Since we assume that the hazard rate is constant over time, the log-likelihood function for a transition parameter λ will be a function of the frequency of observing transitions to the total time exposed to the risk of transition. Assume we observe an uncensored individual moving from unemployment to employment after a duration of t_1 in unemployment. The likelihood contribution consists of:

- the probability of transition (with probability λ_{NC} if the individual finds a job in a non-coal industry and with probability λ_C if the individual finds a job in the coal sector).
- the probability of surviving without having transitioned until t_1 - the survival probability depending on the competing hazards of finding a job in the coal or non-coal sectors. We exclude the possibility of unemployment ending in retirement, a sequence which we define as early retirement.

$$\lambda^{NC} exp \ \left[- \left(\lambda^{NC} + \lambda^{C} \right) \ t_1 \right] \tag{11}$$

We base our estimation on daily transition rates, and use these to calculate monthly transition rates. This allows us to correctly differentiate the informational content of transitions early versus late in the month and we avoid time aggregation bias highlighted by Shimer (2005). To take into account censored spells, we relate the number of transitions, D, to total time at risk T. For details, see appendix (D.2). Given the difficulty of estimating time preference parameters and in line with common practice in the literature, we parameterize the time discount rate with which we discount future utility streams using a monthly discount rate of r=0.05/12.

4 Results

Section (4.1) presents our estimated parameters, the key inputs into the value functions that form the basis of our calculations of welfare loss. Section (4.2) presents our estimated level of welfare cost of job loss and considers what contributes to this welfare loss. Section (4.3) shows how welfare costs vary across individuals and macro-economic conditions. Section (5.1) considers how total welfare costs of the population vary as we delay exiting coal. Finally, section (5.2) consider a labor market policy to alleviate welfare costs.

Table 2: Parameter estimates

	p.e.	s.e.	hypot. years until event	No. transition/wage obs
δ^C	0.00230	0.00001	36.7	26,151
δ^{NC}	0.01335	0.00003	6.7	176,255
λ^{NC}	0.02737	0.00018	3.5	22,274
λ^C	0.00481	0.00007	17.8	3,877
λ^{ZC}	0.05381	0.00013	2.1	171,762
ρ	0.00211	0.00001	40.0	24,156
w_T^C	2,211	5.56	-	22,272
$w_{t_0}^{NC}$	1,600	4.48	-	15,391

Notes: p.e. - point estimate of monthly transition rates (calculated from daily transition rate); s.e. standard error, λ^{NC} non-coal job finding rate for unemployed coal workers; λ^C coal job finding rate for unemployed coal workers; λ^{ZC} non-coal job finding rate for unemployed non-coal workers; δ^C - job destruction rate in the coal sector; δ^{NC} - job destruction rate in other industries; ρ old-age retirement rate out of the coal sector; w_T^C - mean coal wage pre-unemployment; $w_{t_0}^{NC}$ - starting wage in non-coal after unemployment in coal. The results in the third column are based on daily transition rates λ (not reported), noting $E(dur) = 1/(1-(1-\lambda))^{365}$. Each observation of the estimation sample (see table (1) is informative for (at least one) transition parameters, while the number of transitions is important in calculating standard errors. The number of wage observations is the number of spells used in estimation of the wage parameters w_T^C & $w_{t_0}^{NC}$).

4.1 Transition rates

Table (2) shows estimates for transition rates and mean wages for the whole population. The third column translates the Poisson rate into average duration until a particular realization. Note that risks are competing in the sense that for example, average job tenure depends on the first realization of either retirement or job loss.

The overall likelihood of retiring implies that workers retire every 40.0 years out of the coal sector. Note that this figure reflects the combined transition rates of both direct transitions out of coal employment and into retirement and indirect transitions out of coal employment whereby older workers quit the coal sector and start an active-labor market policy, marginal employment (minijob) or become unemployed before moving into retirement. Given the reduced job-search requirements imposed on older workers, the latter sequence of transitions (coal-sector employment followed by unemployment followed by retirement) is used by employers as a means to save on early retirement costs.

Job security is much higher in the coal sector than in non-coal jobs. Estimated transition rates imply that coal workers lose their job only every 36.7 years, whereas non-coal workers are predicted to lose their jobs every 6.7 years.[11]

Coal workers are less likely to lose their job, but when they do, they are also less likely to find a new one: While $\lambda^{\hat{ZC}}$ implies that workers who lose their non-coal job find a new job after an average of 2.1 years, former coal workers need an average of 3.5 years before they are re-employed. The vast majority of jobs that former coal workers find are not in the coal sector, as a comparison of the transition rates $\lambda^{\hat{NC}}$ and $\lambda^{\hat{C}}$ reveals. This explains why the welfare results do not change much depending on whether we assume that unemployed workers may or may not regain employment in the coal sector (see the discussion in section (E.1)).

How do these figures compare to other studies of the German labor market? As noted above and discussed in section (3.1), our sample includes all workers who worked in the coal sector at one point in their career in our observation window. Nevertheless, labor market dynamics in the non-coal sector appear largely representative of the broader German labor market. Appendix table (7) contrasts our findings of flows into and out of unemployment with other studies on German data over a similar periods.

[11] Note that our estimated rate concerning non-coal jobs is based on employment relationships that might reasonably be alternative for coal workers: We only analyze non-coal jobs of workers who were employed in the coal sector at some point in their career.

First, regarding job finding by former non-coal workers, our estimate of $\lambda^{\hat{Z}C}$ implies an average of 2.1 years in unemployment. Elsby et al. (2012) report an average unemployment outflow implying 1.4 years in unemployment; Hobijn and Sahin (2007) find 1.2 years and Nordmeier (2014) finds 0.8 - 2.1 depending on the specification.

Second, for job loss, the variation of reported values in the literature is larger. Our estimate of job loss of non-coal workers, $\delta^{\hat{N}C}$, implies job loss on average every 6.7 years - this compares to rates values of 16.7 years (Elsby et al., 2012), 7.9 years (Hobijn and Sahin, 2007) and 6.9-11.8 years (Nordmeier, 2014). The order of magnitude of our findings is consistent with the literature.

When former coal workers subsequently find employment, earnings are found to be on average 27% lower after unemployment, with the distribution of coal earnings dominating that of other jobs - as can be seen by comparing the distributions in figure (2).

Table 3: Welfare cost of losing a coal job

	Value Coal Job	**Value Unemp**	**Welfare Cost**
Baseline Estimate	257,254	101,970	155,283
Counterfactuals:			
(i) Same Wages	257,316	129,076	128,240
(ii) Same Job Loss δ	257,463	192,663	64,800
(iii) Same Wage & Job Loss δ	257,606	254,194	3,411

Notes: Welfare costs in 2010 Euros based on equation (1) using estimated parameters presented in table (2). Counterfactual (i) replaces parameters of $F^{NC}(.)$ by $F^{C}(.)$; counterfactual (ii) replaces δ^{NC} by δ^{C}; counterfactual (iii) implements combines both counterfactual replacements of (i) and (ii).

4.2 Decomposing welfare costs of job loss

Across the population of coal workers, line 1 of table (3) presents the average discounted value of a job in the coal sector as €257,254. After job loss, the expected income stream in unemployment is worth €101,970, implying a welfare cost of job loss of €155,283.

How can we make sense of this figure? With average earnings of €2,211 in the coal sector, the welfare costs correspond to 5.8 years of earnings, or around 20 years of discounted value of the difference between earnings in the coal and non-coal sectors. Another perspective is that the government has communicated costs of around €5bn for early retirement subsidies for an estimated total of around 40,000 workers in the coal sector (including hard coal and power plant employees, Bundestag (2018)). This translates to €125,000 per worker. The comparison highlights that the government is prepared to pay similar figures to compensate workers - though the programme only covers workers aged 58 and above.

What are the causes of this welfare cost? The welfare loss has three causes: First, a period of unemployment in which income is lower than in coal-sector employment. Unemployment duration depends on λ^{NC} in particular.[12] Second, after finding a job in the non-coal sector, former coal workers may face lower wages on average. Third, job security in the non-coal sector may be lower than in the coal sector.

The latter two reasons thus refer not to the period of unemployment but to the quality of employment that former workers obtain upon rejoining the workforce. Counterfactuals (i) and (ii) in table (3) allow us to quantify the relative contribution of these two effects. Counterfactual (i) presents the results of a calculation of the value of coal job and the value of unemployment under the assumption that workers draw job offers from the same wage offer distribution that governed former earnings in the coal sector. The third column of counterfactual (ii) gives the (hypothetical) welfare cost of losing a coal job under the assumption that jobs found out of unemployment pay on average the

[12] In appendix (E.1) we show that results change only little if we allow workers to rejoin employment in the coal sector, since recruitment out of unemployment is rare.

same as coal jobs. Unsurprisingly, the value of coal-sector employment is little affected - this is because coal workers rarely lose their job and therefore are unlikely to benefit from higher wages in the non-coal sector. By contrast, the value of unemployment rises from €101,970 to €155,283 as unemployed workers may find better jobs. As a result, welfare costs of job loss fall by 17.4% to €128,240.

Similarly, counterfactual (ii) in table (3) shows the effect of assuming that former coal workers benefit from the same level of job security in the non-coal as in the coal sector. Here we find welfare costs fall by over half compared to the baseline: Fully 58.2% of welfare costs of job loss are a result of workers facing a lower level of job security in non-coal sector. Note that risk averse workers may derive further value from the more secure income streams than our risk-neutral estimates reveal.

Finally, counterfactual (iii) in table (3) shows how welfare costs are nearly completely explained by the combined effect of lower wages and lower job security in the non-coal sector. Welfare costs fall to €3,411, indicating that individuals are hardly better off in their coal job than in unemployment. The remaining welfare cost relates to the period in unemployment and associated lower income streams. Our results are consistent with those from Schmieder et al. (2018) based on mass layoffs across German industries, where "almost all of the long-term losses in earnings are explained by lower wages among the displaced workers, rather than by employment losses."

The contribution of time spent in unemployment is a negligible factor in explaining the welfare cost of job loss. The most important determinant of welfare costs is not the time spent searching for a job, or the level of benefits, but the lack of jobs with high wages but especially a high level of job security. Note that by focusing on the net present values without taking into account attitudes to risk, these results somewhat understate the importance of job security in real welfare loss.

4.3 Variation in welfare costs of job loss

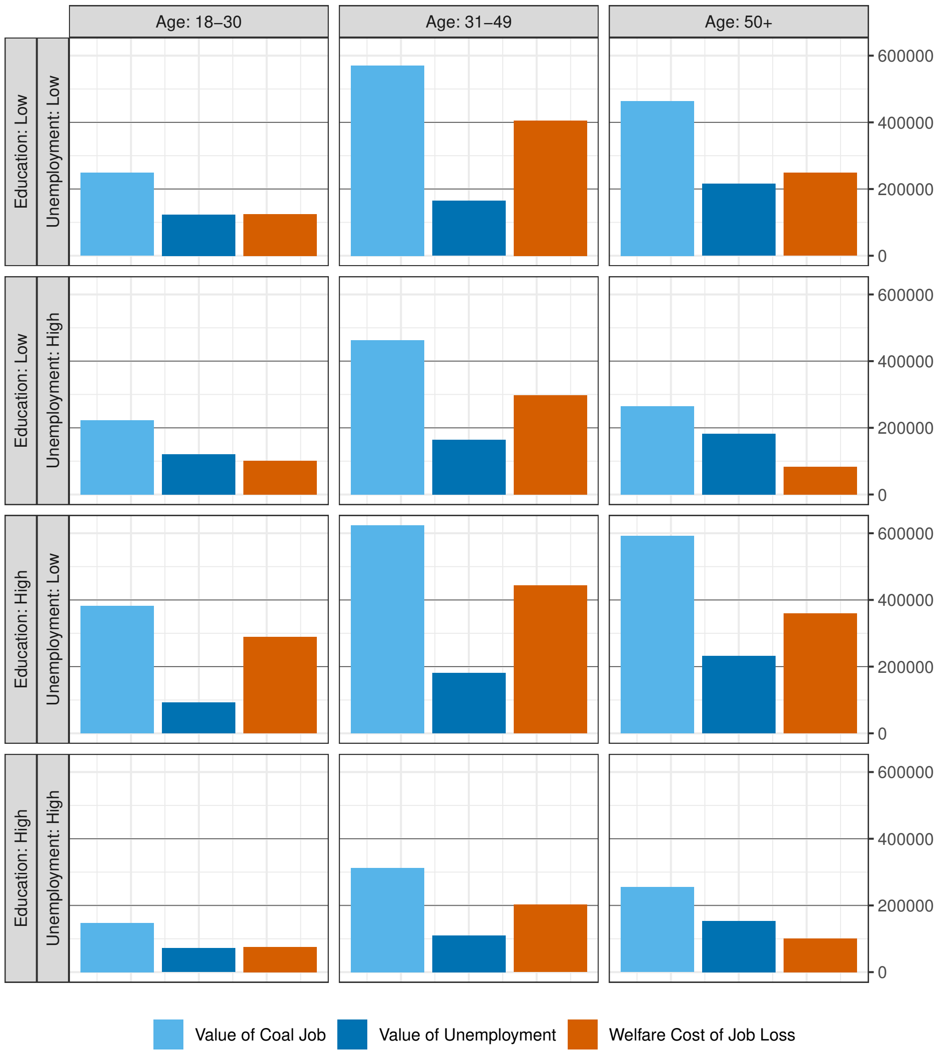
Table (4) contrasts welfare costs of job loss across different socio-economic groups and macro-economic conditions. The greatest welfare losses are suffered by high-educated workers aged 31-49 in periods of low unemployment. It may seem surprising that these high welfare losses arise in periods of *low* unemployment. In fact, we find a consistent pattern of higher welfare losses in periods of low unemployment. Why are welfare costs of job loss higher in periods of lower unemployment, when it is presumably easier to find alternative job?

While the value of unemployment is indeed higher (the likelihood of finding a job is higher, and the quality of jobs on offer in terms of wages and job security is also higher), this effect is dominated by the increase in value of coal-sector employment in times of low unemployment. An inspection of lines 9 and 10 in table (4) reveals this relationship between macroeconomic conditions and welfare costs that holds for other groups also. In good times, unemployment is less problematic, but job security is also higher, thus increasing the value of a relatively high wages associated in the coal sector. Our findings are not inconsistent with other studies that consider the role of the business cycle on earnings and wage loss but do not consider job security as a job characteristic, e.g. Schmieder et al. (2018).

Comparing differences across age groups, welfare losses are lower at both ends of the age spectrum - with the lowest values recorded for high-educated workers aged 18-30 and low-educated workers aged 50+. This is part of a pattern of higher welfare costs for workers in the middle of the age range (31-49 years old have on average welfare costs of €337,569 across groups of education). Younger workers have less job security and lower wages in the coal sector, reducing the welfare costs (on average €147,870). Older workers have higher wages but their participation horizon is shorter as retirement looms (on average €197,930).

Comparing welfare costs by level of education, we find higher welfare costs for high-educated workers. Differences here are less striking, however, with the mean of the welfare loss of low-educated worker groups at €210,259 compared to a mean of €245,063 in the groups of workers with higher formal education. Wage variation across different age groups are much larger than across different educational outcomes - suggesting important returns to tenure and experience in the industry.

Table 4: Welfare cost of losing a coal job - by groups (€)



Notes: Welfare costs based on by equation (1) using estimated parameters reported in appendix table (9).

5 Policy Simulations

5.1 Timing of coal exit

The welfare costs of job loss are often cited as an argument for delaying policies to exit rapidly from coal. The framework presented here allow us to analyze the relationship between speed of coal exit and resulting welfare costs for workers.

First, the costs of an immediate coal exit can be interpreted as the sum of welfare costs of job loss for all employees. Applying the group-specific welfare costs of job loss presented in the previous section to the current workforce[13], we find total welfare costs of €4.15bn of an immediate coal exit. To the best of our knowledge there are no other estimates of the total welfare costs for workers. While our figure may appear high, transfers to workers via the early retirement programme are expected to reach very similar levels, as we show below when we present our projected welfare costs for a coal exit in 2035/2038.

To compare this figure to later exit dates, we consider how many workers are predicted to be working in the industry in the future and their associated welfare costs. In line with previous sections, welfare costs are here assimilated with the situation of leaving a coal job to unemployment. Job loss due to coal exit may of course be different from other job loss: On the one hand, a coal exit that has been announced a long term in advance may lead to smaller reduction in costs as workers can search for follow-on jobs early on. On the other hand, opportunities for alternative employment may be negatively affected if many workers search for alternative employment at the same time. On balance, we feel these figures give a good indication of the associated welfare cost. In practice, firm or state policies are frequently implemented to reduce these costs. Our analysis in this section should be understood as the unabated welfare costs for workers in absence of policy interventions.

To model the evolution of the workforce, we project departures based on workforce

[13] Our latest data are from 2017.

aging and the estimated frequency of retirement[14] and assume that coal firms do not recruit new workers. While certain recruitments are inevitable to continue efficient production, firms have a particularly effective instrument at their disposal: The vast majority of workers retire early, and these retirements occur by mutual consent of firms and workers.[15] The age distribution of the coal industry means that departures to retirement are an important factor in modeling the evolution of industry employment.
We base our calculations on the group-based results from section (4.3), with one exception: In simulating retirement probabilities, we want to take into account the effect of workforce aging on retirements more precisely than we can by pooling the group of 50+. For our projections, we therefore use more detailed age-specific retirement probabilities for ages 50-65 and that workers retire at the latest with 65 years of age. This strategy allow us to take into account how workforce aging in the group of workers aged above 50 influences average retirement probabilities across the population. Taking the population in 2017, we apply these group- and age-specific retirement probabilities and simulate how the aging of the workforce changes the sizes of different age groups. Since section (4.3) also finds large differences in welfare costs across different age groups, we also take account of the changing composition of the workforce remaining in the coal industry when calculating total welfare costs of different coal exit dates.

Figure (3) presents our results, where we first focus on the baseline ("without WIS"), section (5.2) discusses the wage insurance scheme (WIS) policy. Our simulations predict that the workforce falls by over 50% between 2017 and 2030, and to under 30% of the initial workforce in 2040. Starting from an initial total of 10,829 coal workers in 2017[16] we project that the size of the workforce drops to 4,941 in 2030 and 3,163 in 2040. As later exits thus affect fewer workers, different exit scenarios translate to different population-wide welfare costs. Following our model, we approximate the financial situation after job loss - in absence any compensation - by the value of unemployment. Estimated total

[14]Section (5.2) considers the effect of an additional policy-induced channel of job-to-job mobility.

[15]A detailed analysis of the early retirement system is presented in Haywood et al. (2021).

[16]Note that due to sample size restrictions, we follow the same strategy as in section (4.3) and calculate age-specific retirement rates only for men who make up 89% of the workforce. We apply a scaling factor to reach population figures.

welfare costs fall to €2.19bn in 2030, i.e. around half of the value we find for an immediate coal exit (estimated at €4.15bn), to €1.45bn in 2038 and further to €1.31bn in 2040.

The timing of coal exit was starkly fought over at least since a government commission started devising an exit plan in 2018. The fairly large reduction in welfare costs that we find over time rationalizes this position. A German coal exit 2030, in line with the 1.5° target of the Paris agreement (Parra et al., 2019) and demanded by international bodies including UN and IMF is predicted to cause welfare costs 33% greater than the government's plan of coal exit in 2038.

Despite the higher costs of a more rapid coal exit, the welfare costs to workers of an immediate coal exit (€4.15bn) are not large compared to the costs of measures implemented for the coal exit 2038: The government's planned spending on support for lignite miners (around €1.61bn[17]) for a coal exit 2038 is remarkably similar to our estimated welfare cost of €1.45bn. However, the funds spent by the government do not cover all workers - only workers aged 58+ are eligible. Therefore our calculations suggest that eligible (older) workers are likely overcompensated with respect to their welfare cost at the expense of younger workers. Welfare costs may be reduced more equitably and efficiently with other labor market policies, as we highlight in the following section.

5.2 Wage insurance for just transitions out of coal

Various policies have been put forward to accompany workforce transitions. The current path chosen in Germany has a strong focus on early retirement, a natural idea given the demographics of the workforce of coal miners, as highlighted in section (3.1).[18] However, welfare costs of job loss were found to be highest for the population of workers

[17] The federal government calculates cost of around €5bn for a programme of subsidised early retirement for up to 40,000 workers (including hard coal and power plant workers), which corresponds to €1.61bn for 12,909 lignite miners. See Bundestag (2018).

[18] We present a simple evaluation of subsidized early retirement in Haywood et al. (2021). We conclude that it is unclear whether this is a promising strategy to reduce employment above already occurring retirement. We find that workers retire on average at 58 in absence of early retirement programs.

in their thirties and forties. We propose a policy option that promotes career switches rather than retirement. This support would be relevant for workers in the middle of their working life who face the highest welfare costs of job loss. They would receive wage supplements if they took on new jobs rather than retire very early. Such a policy may have positive welfare effects beyond the directly affected workers: by encouraging economic activity in regions particularly affected by the industrial decline of the coal sector. A similar subsidy was available to older unemployed workers in Germany through 2003-2012, allowing job-seekers to move to lower-paid jobs while being paid according to their previous wage ("Entgeltsicherung").

More specifically, we propose that wage bonuses would compensate any wage cuts associated with job moves of coal workers leaving the industry. We call this the wage insurance scheme (WIS). The mechanism is simple: Workers who accept a job receive an income subsidy if their income in their new job is lower than in their previous job. The income subsidy is paid for a limited amount of time (we assume five years) but should significantly increase the incentive to search for a job outside of the coal industry. Furthermore, the scheme will tend to offer most benefits to those who risk losing most as a result of coal exit: Individuals whose wage in the coal sector is particularly high.

To make the simulation tractable, we make some simplifying assumptions about job mobility under the wage insurance (WIS) scheme. We assume that the WIS scheme is generous enough to entice all coal workers to search and accept job offers from non-coal jobs at the same rate as unemployed workers. This may seem ambitious. However, we make this assumption within groups, such that the rate at which coal workers move to non-coal jobs corresponds to the job-finding rate out of unemployment of similarly aged workers with similar level of education. Also, we restrict moves to under-60s.[19] Finally, recall that job-finding rates out of unemployment for coal workers are considerably lower than for the average population, which may be related to the combination of high wages in coal and unemployment benefits.[20]

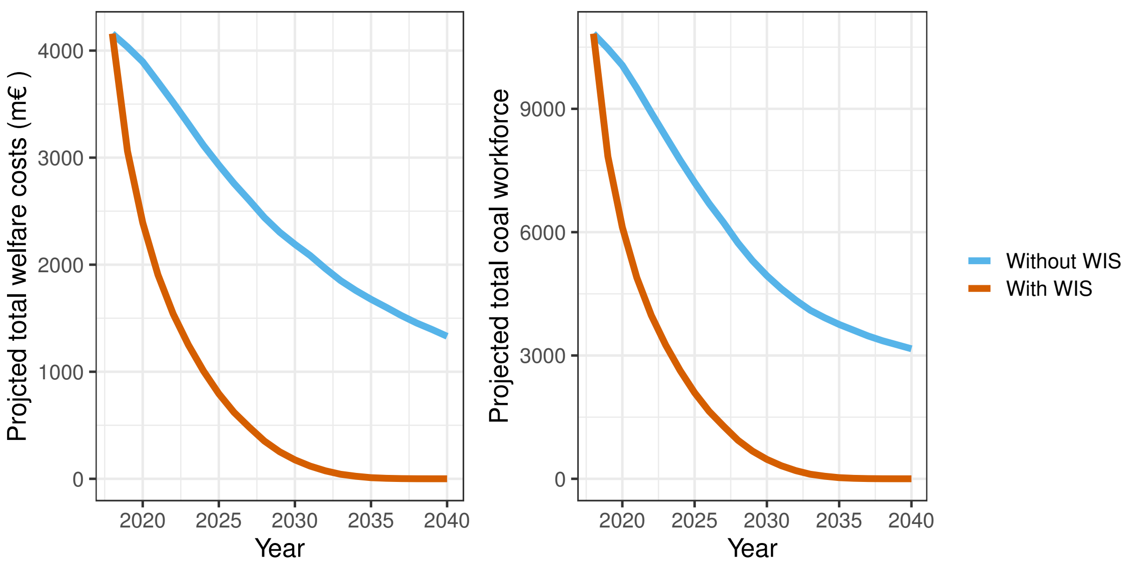
[19]This restriction allows us to assume WIS costs accrue over five years for all individuals without taking a stance on retirement probabilities in non-coal sectors.

[20]The incentives to search for jobs in these two situations depend on various factors. While coal

What is the potential of the WIS policy to reduce the welfare costs of coal exit for coal workers? If we assume that the WIS comprehensively protects workers from future welfare losses, workers who move to other sectors face no welfare costs. The WIS scheme will be successful in reducing welfare costs when many workers - specifically workers with high welfare costs - find jobs in other sectors.

We project future workforce numbers following the assumptions of the previous section. In particular, we assume that the coal industry neither recruits nor lays off workers. Coal workers leave the sector to retire or move to the non-coal sector if such moves are subsidised by the WIS. The find non-coal jobs at rate λ^{NC}. The left panel of figure (3) shows the resulting projected future workforce with the WIS policy. Compared to the status quo scenario, we find faster reduction of the coal sector workforce, with an increasing divergence of trajectories:

Figure 3: Projected workforce in coal sector and welfare costs with & without WIS



workers under the WIS have a stable income stream, unemployed workers receive (lower) benefits, have more leisure time but benefits are limited in time. While unemployed workers may face penalties if they show too little search effort, the efficacy of these search requirements in the German context is disputed.

The WIS policy rapidly reduces employment numbers in the coal industry - by 2025, the projected workforce with WIS is projected to be 70.9% smaller, by 2030 the figure rises to 90.4%, reaching over 99% in 2040.

By enabling coal workers to find other jobs, these are spared from the coal exit, thereby reducing welfare costs. The reduction in welfare costs is presented in the left panel of figure (3) and is largely proportional to the reduction in workforce. Welfare costs are 72.8% lower for a coal exit in 2025 and 91.9% lower than in the status quo scenario by 2030, and less than 1% of baseline welfare costs in 2040.

To assess the opportunity of such a scheme, we now consider the budgetary costs. To calculate the costs of the WIS, we first consider the number of affected coal workers. For this, we use our group-specific job offer arrival rates of non-coal jobs estimated in section (4.1) and the projected population sizes of our groups over the course of the simulation period. The number of individuals moving to another job corresponds to the difference in projected workforces with and without the WIS policy - see the right panel of figure (3).

Second, the WIS policy we analyze makes payments whenever the offered wage in the non-coal sector $w^{NC}(x)$ is below the wage in the coal sector. We use the distribution of observed non-coal industry wages, assuming that offers in non-coal industries are not influenced by WIS. In other words, coal workers draw from the group-specific distribution of wages in the non-coal sector $F^{NC}(.,x)$ we estimate above. Wage offers arrive with probability λ^{NC}. A fraction $F^{\bar{N}C}(w^C(x),x)$ of non-coal offers exceed the current wage level in coal w^C for an individual with characteristics x, where $\bar{F} \equiv 1 - F$. Summing over different wage levels, the probability that a job-to-job transition will result in WIS payments for an individual x is $\int F^{NC}(w^{\bar{\prime} C}(x),x)dF_C(w'^C,x)$.

Finally, the size of the payments is a result of the sum of the wage differentials of the two log-normally distributed wages $w^{NC}(x)$, $w^C(x)$ conditional on this difference being positive.[21] We assume these payments are made for five years.[22]

We find that while substantial, costs are nonetheless a fraction of welfare gains for all our exit scenarios shown in figure (3): Costs for an WIS amount to €615.4m if the programme is run until 2030, or €615.7m if the programme ends in 2040. Costs consist of payments of monthly payments averaging €1,389.6 per month across groups and paid for 60 months to 4,793 workers. Full results specifying WIS costs for different groups are relegated to appendix table (10). These costs can be compared with the reductions in welfare costs achieved by the WIS, which amount to over €2bn for a coal exit in 2030, and €1.36bn for a coal exit in 2040 - indicating a cost-effective way of reducing welfare costs.

The WIS policy reduces welfare costs by more than it costs because it mobilizes productive capacity. The insurance allows workers to step out of their industry sooner, reducing the inevitable job loss in coal.[23] Finally, detailed results by groups (see appendix table (10)) show that 63% of WIS beneficiaries are younger than 50 years of age - groups that are not entitled to the most common labor market policy used to cope with industrial decline, subsidized early retirement, despite welfare costs exceeding those of older workers.

Our figures may overstate the potential of the WIS policy to reduce coal employment if job-finding rates out of coal employment are not as large as out of unemployment. If the monetary incentives of the WIS give rise to less search effort than unemployed workers show, workforce and welfare costs will be lower - we test an alternative scenario in

[21] As Dufresne (2004) notes, "the convolution of log-normal distributions does not have a simple explicit expression. We follow standard practice by fitting a log-normal distribution to the distribution of wage differences". We estimate the latter distribution by simulating wage differences.

[22] Note that individuals may receive (gross) wage increases or move to better-paid jobs thus decreasing the cost. They may however also lose their job in which case the WIS as a "wage insurance" would increase payments. On balance, assuming a cost of five years the wage differential (if negative) appears reasonable.

[23] Note that the financial gains do not take into account that workers have less leisure when they accept another job than without the scheme. Remaining active in the labor market may be a worthwhile policy objective for other reasons too, however - not least for the non-financial benefits it can provide workers.

which employed coal-workers only receive half as many offers as unemployed workers in appendix (E.2). While we find effectiveness is indeed reduced, it falls less than proportionally to the job-to-job transition rate. Importantly, the instrument remains highly cost-effective, since budgetary costs fall alongside the number of workers making use of the WIS scheme.

6 Conclusion

This paper proposes a simple stochastic labor market model to determine welfare costs of job losses for workers resulting from industrial decline. The model allows us to distinguish the contribution of unemployment and lower job quality in alternative jobs. We estimate the model using observed transitions and associated wages to simulate the costs of a job loss in terms of forgone earnings and worse employment opportunities. We use our simple strucural model to evaluate a subsidy for workers to take on alternative employment. We find this wage insurance scheme can greatly reduce the welfare costs of industrial decline at litte fiscal cost. We show how an aging workforce reduces costs of final closure of an industry as a function of the speed of industrial decline.

We present results for the German coal industry. We calculate the value of employment in this industry for different types of workers at different points in the business cycle. We show how costs vary across individuals and find for example that middle-aged workers are most affected. Without any active policy intervention, we predict a rapid reduction of the workforce (-50% by 2030) due to the combination of the retirement of older workers and our assumption that no workers are recruited. This leads to considerable reduction in workers affected by coal exit over time, and with that welfare costs - while an immediate coal exit causes €4.15bn, by 2030 this figure is reduced to €2.19bn.

We leverage our simple model framework to simulate welfare cost reductions that can be achieved by a wage insurance scheme that may encourage continued labor market participation of coal workers in other industries. We find that welfare costs can be reduced considerably - by over two thirds. Associated welfare gains (€1.3-2bn) could be achieved at relatively low cost (roughly €615) to the public purse.

Our model and results appear relevant for other settings of industrial change: The alternative options available to workers in terms of wages and job security as a function of their age, education and the business cycle are likely to be important contributors to welfare costs of other industrial declines. The advantages of a wage insurance as a labor market policy instrument may apply there also.

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A Details on derivation

We here adopt the standard notation $\overline{F} \equiv 1 - F$, and note that $\overline{F}(\overline{w}) = 0$ and $\overline{F}(\underline{w}) = 1$ by the definition of $\overline{w}$ and $\underline{w}$ as the upper and lower support of the wage distribution and assuming a continuous distribution without mass points. The following derivations are valid for both $V^{NC}(x)$ and $V^{C}(x)$:

$$\int V(x)dF(.) = \int V(w') \ \left(-\overline{F}'(w')\right) dw' \tag{12}$$

$$= \left[V(w') \ (-\overline{F}(w'))\right]_{\underline{w}}^{\overline{w}} - \int V'_M(w') \ (-\overline{F}(w'))dw'$$

$$= \left[V(\overline{w}) \ (-\overline{F}(\overline{w})) - V(\underline{w}) \ (-\overline{F}(\underline{w}))\right] - \int V'(w') \ (-\overline{F}(w'))dw'$$

$$= V(\underline{w}) \ \overline{F}(\underline{w}) + \int V'(w') \ \overline{F}(w')dw'$$

$$= V(\underline{w}) + \int V'(w') \ \overline{F}(w')dw' \tag{13}$$

$$= V(\underline{w}) + \frac{1}{r+\rho+\delta} \ \int \overline{F}(w')dw' \tag{14}$$

Where we move from (13) to (14) since the value of employment (3) implies that $V'(w') = \frac{1}{r+\rho+\delta}$, such that for the two sectors we have $V'^{NC}(w') = \frac{1}{r+\rho+\delta^{NC}}$ and $V'^{C}(w') = \frac{1}{r+\rho+\delta^{C}}$.

B Value of unemployment

The expression for the final (stationary) period is given by (8). Now consider the before-last period of unemployment B_{M-1}. Using the general Bellman equation for unemployment at any point of time during the duration of unemployment (5) we find

$$B_{M-1}(x) = \frac{b_{M-1}(x)}{1+r} + \frac{\lambda^{NC}}{1+r} \ \int V^{NC}(w',x) \ dF^{NC}(w') + \frac{\lambda^{C}}{1+r} \ \int V^{C}(w',x) \ dF^{C}(w') + \frac{1-\lambda^{NC}-\lambda^{C}}{1+r} B_M(x) \tag{15}$$

and

$$B_{M-1} - B_M = \frac{b_{M-1} - b_M}{1+r} \tag{16}$$

$$B_{M-1} = B_M + \frac{b_{M-1} - b_M}{1+r}. \tag{17}$$

Analogously, we can state the value of unemployment for period $M-2$ as

$$B_{M-2} = B_M + \frac{b_{M-2}(x) - b_M(x)}{1+r} + \frac{1-\lambda^C-\lambda^{NC}}{1+r}\frac{b_{M-1}(x) - b_M(x)}{1+r} \tag{18}$$

and the reduction in value of being unemployed for $M-2$ versus $M-1$ periods as

$$B_{M-2} - B_{M-1} = \frac{b_{M-2}(x) - b_{M-1}(x)}{1+r} + \frac{1-\lambda^C-\lambda^{NC}}{1+r}\frac{b_{M-1}(x) - b_M(x)}{1+r} \tag{19}$$

We could now continue to use this to express $M-3$ as a function of B_M and b_{M-3}, b_{M-2}, b_{M-1}, b_M and work our way back to the value of B_0. The pattern that emerges is that the value of unemployment for periods $M-t$ where $t = 0, ..., M-1$ can be written as

$$B_{M-t} = B_M + \sum_{i=1}^{t}\left(\frac{1-\lambda^{NC}-\lambda^C}{1+r}\right)^i \frac{b_{M-(t-i)} - b_M}{1+r} \tag{20}$$

To build an intuition for this expression, note that the second term on the right-hand side is constant across the twelve periods preceding M: In every of these periods, individuals gain 60% of their previous income rather than a fixed rate of €800. As an illustration, across the whole population, average income is €2,211. This implies an income loss of €526 when moving from 12th to 13th month of unemployment. This reduction is anticipated in a discounted manner in earlier periods - with discounting related to time preferences (r) but also the chance of finding a job in the coal (λ^C) and non-coal (λ^{NC}) sectors.

Table 5: Distributions of wages pre- and post-imputing top-coded wages

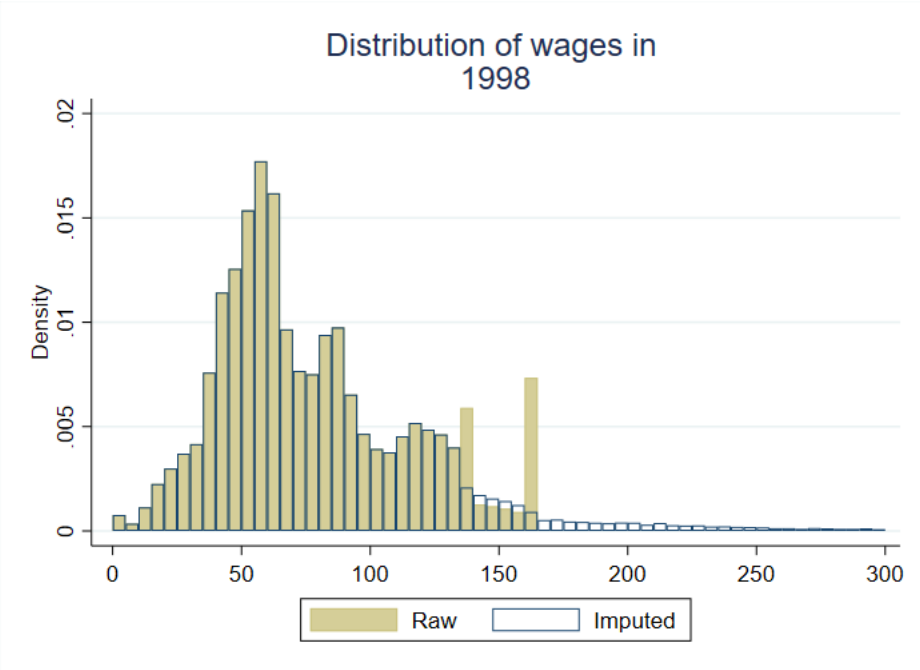
	pre imputation	after imputation	N
mean wage coal (w_T^C)	2,209.69	2,211.94	22,272
mean wage non-coal ($w_{t_0}^{NC}$)	1,595.97	1,600.43	15,391

Notes: All wages in 2010 Euros.

C Treatment of top-coded data

For around 7% of all wage observations we observe wages at or above the upper assessment limit, with important variation by age (only 1% of individuals younger than 30

Figure 4: Pre- and post-treatment of top-coded data - 1998



being subject to top-coding). For these observations, we replace values by imputed values. We impute censored wages using separate regressions for women and men, East and West Germany, and by decade. Within these stratified samples we run Tobit regressions based on individual characteristics. We specify a particularly flexible specification for age, the most important determinant of censoring. We include a linear and quadratic term for age below 40 and different terms for age above 40. We also include a quadratic specification for general labor market experience, as well as dummies for three different formal educational outcomes.

The imputed values considerably increase wage levels in the group of censored observations, raising mean wages from €5,258 to €7,955. However, as only a small fraction of observations is concerned, mean wages overall change little. The specific inputs into the welfare cost analysis - coal wages and non-coal starting wages - also change only little, as table (5) reveals.

As an example of the effects of this treatment, figure (4) shows the distributions of the raw and treated wage distribution for the year 1998. As the assessment ceilings vary across years, pooling years is not practical here.

As a result of these small changes due to imputation on aggregate wage distributions, welfare costs across cells will also be little affected. Note that our treatment of top-censoring could have an effect on welfare costs in cells because we use the mean of the log-normal distribution and top-censoring will influence the parameters of this distribution and hence the calculated mean and variance of the distribution. In practice, few observations are affected and the ordering of welfare results across groups does not change as a result.

D Details on Estimation

D.1 Macroeconomic conditions and censoring

We are stratifying our sample by macroeconomic conditions, thus implying that parameter values may be different at different points in time. This also implies that we must take care to use the correct information when estimating these parameters. Labor market spells lasting across different macro-economic conditions thus contain information for estimation of several parameters across several periods.

As an example, assume an individual has been unemployed for $t = 10$ years, this first 8 years in bad macroeconomic conditions and the last 2 years in good macroeconomic conditions. Parameter values in bad macro conditions are designated by cell $c = A$, good macro conditions in cell $c = B$.

Then for estimation of λ we want to use only the duration $t_2 = 2$ in estimation of cell B (the memoryless characteristic of the Poisson distribution assures that we need no further treatment of the likelihood in this case). Analogously, the duration in the previous macroeconomic conditions in our case $t_1 = 8$ months, is a right-censored observation used in the estimation of cell A.

$$\lambda_B^{NC}\ exp\ \left[-\left[\lambda_B^{NC}+\lambda_B^{C}\right](t_2)\right] \tag{21}$$

$$exp\ \left[-\left[\lambda_A^{NC}+\lambda_{c=A}^{C}\right]\ t_1\right] \tag{22}$$

We treat these spells as censored and assume random censoring: We have around 3.26% of spells spanning across different macroeconomic conditions during a spell and these are thus censored.

D.2 Details on estimation of transition parameters

A simple (consistent) estimator for a Poisson transition rate is based on the mean duration before a transition: To estimate the probability of transitioning out of unemployment, consider average duration in unemployment. We also wish to take into account right-censored data however. We have many observations for which we know that individuals were at risk of a transition during a certain time but then their status ended for other reasons. Individuals may be lost to attrition or the end of the sample observation period may be reached. We therefore carefully account time-at-risk and use this to estimate the transition probabilities:

The likelihood function for censored Data: Assume that the risk is constant over time, so we denote the hazard rate by $\lambda(t) = \lambda$ for all t. The corresponding survival function is $S(t) = \exp(-\lambda t)$. This is the exponential distribution with parameter λ. The density may be obtained by multiplying the survivor function by the hazard $f(t) = \lambda\ \exp(-\lambda\ t)$.

Our sample of N censored observations has an exponential distribution. Let t_i =the observation time and d_i = the transition indicator for spell i.[24] The log-likelihood function is

$$log\ L = \sum_i d_i log\ \lambda - \lambda\ \sum_i t_i \tag{23}$$

[24]The origin of this standard notation is survival analysis where transitions are deaths.

Rewriting the log-likelihood using for total number of transitions $D = \sum_t (d_t)$ and for total exposure time $T = \sum_i (t_i)$ we then have

$$log\ L = D\ log\lambda - \lambda\ T. \tag{24}$$

Setting the FOC with respect to λ to zero, we find the following maximum likelihood estimator of the hazard rate as

$$\hat{\lambda} = D/T. \tag{25}$$

Using the derivative of the score we can also derive the asymptotic standard error as

$$SE_\lambda = \frac{\hat{\lambda}}{\sqrt{D}}. \tag{26}$$

Note that estimation and inference of the transition rates thus requires calculating total exposure time, i.e. the time at risk of transition. (If there were no censored spells, we would not need to do this.) Time at risk varies for each parameter:

- For transitions to retirement (ρ), time at risk is any time in coal employment.
- For job loss in coal(δ^C), time at risk is any time in coal employment.
- For job loss in non-coal (δ^{NC}), time at risk is any time in non-coal employment.
- For job finding post-coal (λ^{NC} and λ^C), time at risk is any time in unemployment following a coal job.
- For job finding for workers who lost a non-coal job (λ^{ZC}), time at risk is the time in unemployment following a non-coal job.

Table (8) reports the number of transitions and the time at risk relevant for the estimation of the different transition rates, by individual characteristics.

Finally, early retirement is not uncommon from the coal sector. This typically takes the form designated somewhat misleadingly "old-age part-time work" and involves individuals accepting a modest pay cut (typically 10-20% of net income) during a period of somewhere between 1-10 years, and then working full-time during half that period before retiring for good. While individuals may be officially employed and paying contributions during their whole early retirement period, they are no longer at risk of losing their job or retiring after half the time. We make assumptions following a typical set-up of early retirement. When we observe employees entering early retirement, we thus assume effective retirement at the midpoint of the duration in early retirement (which we have in the data). For the retirement probability, the time at risk includes the duration until this mid point. Also, we consider that once people are in early retirement, the only exit is retirement. These persons are not at risk of losing their job or finding a job. The periods in ATZ are thus not included in the calculation of the exposure time for the job loss rate and the job finding rate.

E Further results

E.1 Results with coal-sector job offers

In the baseline results, we assume that individuals may not find coal jobs out of unemployment. A part of the welfare costs of coal exit are thus omitted, since individuals previously may have been able to find coal-sector jobs out of unemployment.

The results in this section allow for coal-sector jobs to be found out of unemployment. Since the job-finding rate of coal jobs is relatively small, this does not affect results strongly.

Note that these results allow us to contrast the baseline welfare costs with two alternative concepts: First, we could hold the optimistic view that coal-sector jobs will be replaced one-for-one by other jobs. In that case, welfare costs would be correctly assessed by the third column of table (6). Second, welfare costs could be construed to be the difference between the value of unemployment $B_0(.)$ post-coal-exit and the value of coal employment, $V^C(.)$, pre-coal-exit. Welfare costs using this definition would combine the baseline value of $B_0(.)$ with the values of V^C given in table. This view would be a step towards the total costs of coal exit including not only individual loss of employment, but also worsening of perspectives in employment. Since we focus on the individual costs of job loss, we do not take this path. However, the estimated welfare costs according to this definition are of similar magnitude.

Table 6: Welfare cost of coal job loss - with option of rejoining coal industry

	Value Coal Job	**Value Unemp**	**Welfare Cost of Job Loss**
Coal-Job-Baseline	257,303.60	123,281.63	134,021.97
Counterf. Same wages	257,357.92	146,795.34	110,562.57
Countf. Same Job Loss	257,485.15	201,877.49	55,607.66
Countf. Same w & Job Loss	257,608.61	255,322.32	2,286.28

Notes: Welfare costs based on equation (1), using .estimated parameters presented in table (2), now including $\hat{\lambda_C}$ in job-finding rate out of unemployment.

E.2 Wage insurance scheme: Robustness check low search efficiency

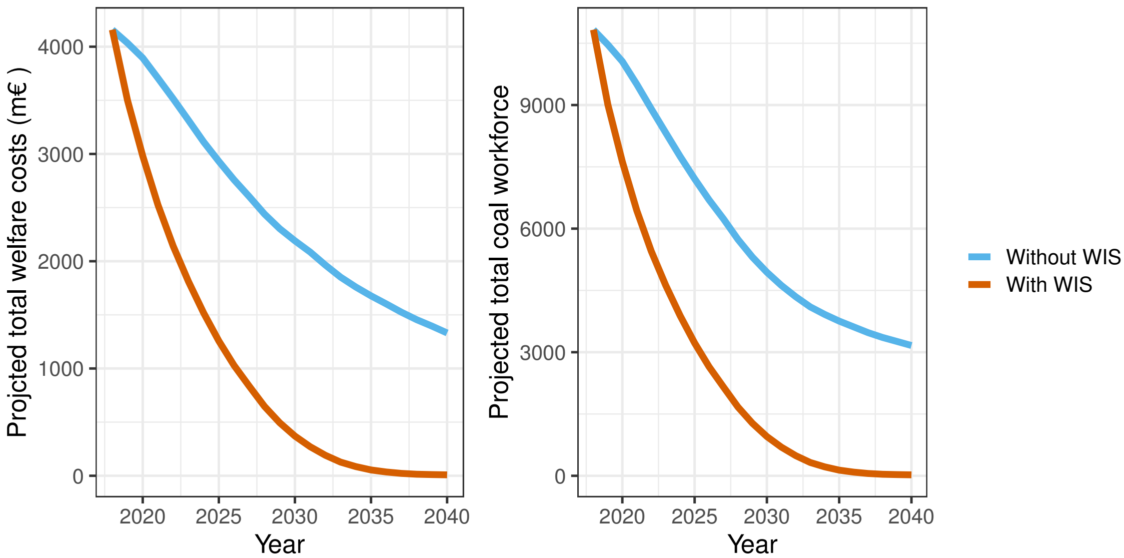
This section presents results when we assume that the wage insurance scheme (WIS) incites fewer job-to-job movements than presented in section (5.2). The WIS provides a complete insurance for any wage losses for five years when coal workers move to a non-coal job. Results in section (5.2) assume that as a result of the WIS, coal workers find new jobs in non-coal sectors at the same rate as unemployed workers of similar age, education and in similar macro-economic conditions. This may be optimistic. We here assume that employed coal workers only display a search efficacy of 50% of unemployed workers.

This has several consequences: First, the reduction in coal workforce is less pronounced: Nevertheless, 4,032 workers (rather than 4,761 in the baseline) workers use the WIS.[25] Relatedly, second, the reduction in welfare costs is smaller. Third, the costs of the WIS are lower.

The cost-effectiveness of the WIS in terms of reducing welfare costs by inciting job

[25] Note that the reduction is less than proportional to the change in the job offer arrival rate. Workers who do not use the WIS in one year may use it in the following year. This is especially true for younger workers, who do not face the competing risk of retirement that older workers face.

Figure 5: Projected coal workforce & welfare costs with & without WIS - low search efficiency



mobility remains intact, as welfare gains are around 2-3 times greater than total costs (€498m) - between welfare costs with and without WIS under the assumptions outlined here (see figure (5)).

E.3 Further figures & tables

Table 7: Estimated transition parameters for Germany (other studies)

	sample period	**monthly transition (hazard rate)**	**time-to-event (years)**
Job finding rate (unemp outflow)			
Elsby et al. (2012)	1983 - 2007	0.06	1.4
Hobijn and Sahin (2007)	1983 - 2004	0.069	1.2
Nordmeier (2014)	1981 - 2007	0.04 - 0.10	0.83 - 2.1
Job loss rate (separation rate)			
Elsby et al. (2012)	1983 - 2007	0.05	16.7
Hobijn and Sahin (2007)	1992 - 2004	0.011	7.9
Nordmeier (2014)	1981 - 2007	0.007 - 0.012	6.9 - 11.8

Table 8: Sample size of different groups x & associated transitions

	Spells	**Pers.**	**Retire**	**Job-loss & Findings**	**Job-Loss & Findings**	**Job-Loss & Findings**	**Job-Loss & Findings**
transition sequence			C-(unemp)-pension	C-Unemp-NC	C-Unemp-NC	NC-Unemp-NC	NC-Unemp-C
informative for			$\rho(.)$	δ^C, λ^{NC}	δ^C, λ^C	$\delta^{NC}, \lambda^{ZL}$	δ^{NC}
1 Low Edu, 18-30, high unem	53,825	18,101	-	647	58	1,036	110
2 Low Edu, 18-30, low unem	33,628	10,670	-	110	7	373	22
3 Low Edu, 31-49, high unem	12,745	6,627	-	484	94	1,019	76
4 Low Edu, 31-49, low unem	12,510	4,709	-	99	6	417	11
5 Low Edu, 50+, high unem	14,616	8,362	3,965	115	46	230	22
6 Low Edu, 50+, low unem	16,348	7,544	510	41	15	189	2
7 Hi Edu, 18-30, high unem	86,053	27,663	-	3,851	490	19,149	791
8 Hi Edu, 18-30, low unem	103,722	27,732	-	197	14	5,463	188
9 Hi Edu, 31-49, high unem	184,679	55,110	-	7,266	1,390	64,040	1,662
10 Hi Edu, 31-49, low unem	230,154	51,946	-	264	29	16,030	257
11 Hi Edu, 50+, high unem	126,202	52,356	14,175	1,982	810	22,108	733
12 Hi Edu, 50+, low unem	188,371	65,515	1,535	133	46	6,878	62

Notes: λ^{NC} - job finding rate in non-coal industries after losing coal job; λ^{C} - job finding rate in coal industry after losing coal job; λ^{ZC} - job finding rate in non-coal industry after losing non-coal job; δ^{C} - job destruction rate in coal industry; δ^{NC} - job destruction rate in other industries; ρ - rate at which individuals retire out of lignite coal;

Table 9: Transition and wage parameter estimates by groups

	1 Lo-Ed 18-30,Hi-Un	**2 Lo-Ed 18-30,Lo-Un**	**3 Lo-Ed 31-49,Hi-Un**	**4 Lo-Ed 31-49,Lo-Un**	**5 Lo-Ed 50+,Hi-Un**	**6 Lo-Ed 50+,Lo-Un**	**7 Hi-Ed 18-30,Hi-Un**	**8 Hi-Ed 18-30,Lo-Un**	**9 Hi-Ed 31-49,Hi-Un**	**10 Hi-Ed 31-49,Lo-Un**	**11 Hi-Ed 50+,Hi-Un**	**12 Hi-Ed 50+,Lo-Un**
δ^C	0.00384980	0.00338721	0.00078947	0.00149689	0.00017161	0.00025091	0.01046265	0.00308678	0.00312916	0.00106800	0.00080782	0.00027494
(s.e.)	0.00014540	0.00031315	0.00003324	0.00014608	0.00001370	0.00003353	0.00015920	0.00021250	0.00003374	0.00006239	0.00001537	0.00002055
δ^{NC}	0.01469680	0.01277801	0.00793699	0.00969128	0.00212569	0.00337102	0.03095093	0.02142038	0.01948297	0.00882501	0.01023320	0.00418057
(s.e.)	0.00043452	0.00064375	0.00024185	0.00046899	0.00013444	0.00024392	0.00022006	0.00028505	0.00007636	0.00006939	0.00006839	0.00005050
λ^{NC}	0.00960126	0.07825839	0.00506182	0.04236632	0.00202446	0.00638949	0.02609981	0.07401724	0.01128780	0.05115885	0.00361615	0.01216308
(s.e.)	0.00554329	0.00405207	0.00253091	0.00187970	0.00101223	0.00049742	0.00556450	0.00120886	0.00199542	0.00058335	0.00073814	0.00024044
λ^C	0.03840504	0.00524520	0.02530910	0.00500390	0.00961618	0.00151024	0.04745420	0.00880547	0.02363384	0.00860740	0.01265654	0.00401633
(s.e.)	0.01108658	0.00104904	0.00565929	0.00064600	0.00220610	0.00024183	0.00750317	0.00041695	0.00288733	0.00023928	0.00138094	0.00013817
λ^{ZC}	0.06746399	0.12355864	0.05488796	0.06408869	0.00603913	0.01574944	0.08917395	0.14851289	0.08299741	0.09257260	0.02916581	0.03096086
(s.e.)	0.01028816	0.00364038	0.00985817	0.00187767	0.00270078	0.00076576	0.00414875	0.00100551	0.00206848	0.00033423	0.00108022	0.00017473
ρ	0	0	0	0	0.00427337	0.00226997	0	0	0	0	0.00395544	0.00229430
(s.e.)	-	-	-	-	0.00006838	0.00010052	-	-	-	-	0.00003418	0.00005858
w_T^C	1762.74	1840.84	2302.13	3210.80	2294.64	3098.25	2142.31	2754.11	2284.72	3292.45	2301.68	3925.92
(s.e.)	34.67	111.08	33.29	72.70	69.18	55.19	7.68	49.63	9.36	73.09	24.04	234.79
$w_{t_0}^{NC}$	1593.29	1951.79	1583.84	2063.96	1486.90	2077.49	1608.11	1997.53	1665.64	2170.72	1731.72	2366.99
(s.e.)	41.10	122.85	36.03	58.53	53.67	161.26	9.82	30.63	6.16	26.60	18.23	79.44

Notes: p.e. - point estimate of monthly transition rates; s.e. standard error, λ^{NC} - job finding rate in non-coal industries after losing coal job; λ^C - job finding rate in coal industry after losing coal job; λ^{ZC} - job finding rate in non-coal industry after losing non-coal job; δ^C - job destruction rate in the coal industry; δ^{NC} - job destruction rate in other industries; ρ - rate at which individuals retire out of coal; w_T^C - mean coal wage pre-unemployment (based on estimated log-normal parameters); $w_{t_0}^{NC}$ mean wage on leaving unemp't post-coal (based on estimated log-normal parameters).

Table 10: Costs & welfare benefits of Wage Insurance (WIS) by groups

	Monthly WIS costs p.p.	**projected WIS users**	**WIS Costs: exit 2030 (m€)**	**WIS Costs: exit 2040 (m€)**
2 Low Edu, 18-30, low unem	1,471.96	305	26.94	26.94
4 Low Edu, 31-49, low unem	1,661.21	341	33.99	33.99
6 Low Edu, 50+, low unem	1,547.34	205	19.03	19.03
8 Hi Edu, 18-30, low unem	1,355.86	693	56.38	56.38
10 Hi Edu, 31-49, low unem	1,638.90	1682	165.40	165.40
12 Hi Edu, 50+, low unem	2,612.20	1567	245.29	245.60

Notes: First Column: Estimated costs for WIS per month per person - this is equivalent to the average wage differential conditional on a higher wage in coal. The third and fourth columns are based on results reported in the first and second columns and 60 months of entitlement period. For information on simulation assumptions, see section (5.2). Groups with poor macro-economic conditions are not displayed, as we project good macro-economic conditions into the future.

F Geographical regions

This study uses three geographical areas to place individuals: Lusatia, Central Germany, Rhineland and "Other Coal regions" - these are the areas in which lignite coal is or was mined in Germany.

Lusatia (Lausitzer Revier) in this study consists of the following administrative regions: Stadt Cottbus and Landkreise Dahme-Spreewald, Elbe-Elster, Oberspreewald-Lausitz, Spree-Neisse, Bautzen, Goerlitz.

Central Germany (Mitteldeutsches Revier) consists of Stadt Leipzig, Stadt Halle and Landkreise Leipzig, Nordsachsen, Anhalt-Bitterfeld, Burgenlandkreis, Mansfeld-Südharz, Saalekreis, Wittenberg, Altenburger Land, Saale-Orla-Kreis.

Rhineland (Rheinisches Revier) consists of Stadt Duisburg, Stadt Köln and Landkreise Rhein-Kreis Neuss, Städteregion Aachen, Rhein-Erft-Kreis, Düren, Euskirchen.

Other Coal Areas consists of Stadt Kassel, Stadt Berlin, Stadt München and Kreise Helmstedt, Börde, Goslar, Hannover, Warendorf, Schwalm-Eder-Kreis, Werra-Meissner-Kreis, Schwandorf, Bad Kissingen, Regionalverband Saarbrücken, Saarlouis, Vorpommern-Rügen, Erzgebirgskreis.