Re-Evaluating British Unemployment Between the Wars

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Abstract

During the 1920s and early 1930s, Britain experienced a severe employment downturn that coincided with the global Great Depression and rapid structural change in the economy. A large literature has debated the extent to which depressed aggregate demand or supply factors contributed to this downturn. This paper presents an alternative perspective on interwar unemployment focused on the role of job and worker reallocation across industries. By digitizing the complete Ministry of Labour *Gazette* data for the first time, a full picture of changes in employment and unemployment in 100 industries can be observed. Using this data, this paper investigates how much job reallocation occurred in interwar Britain and the extent to which different groups of workers were able to transition between industries. I provide new evidence of sectoral-level job creation and destruction, estimate industry-level job finding rates to capture worker reallocation, and use Markov transition probabilities between sectors in a simulation to connect impediments to reallocation to persistent unemployment. I find that the interwar British economy faced allocative shocks that generated significant job creation in some industries and job destruction in others. Impediments to job and worker reallocation in the face of these shocks contributed to high unemployment, but some workers were more affected than others. This new perspective on a key historical employment downturn has implications for historical and modern monetary and fiscal policy.

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1 Introduction

Between World War I and World War II, Britain experienced mass unemployment for over a decade. The unemployment rate climbed to over 23% in 1921 and then did not fully recover, remaining near 10% throughout the 1920s. The Great Depression, though comparatively mild in Britain, intensified unemployment even further, doubling the unemployment rate to 23% by January 1933. Throughout the interwar period, mass unemployment became a pressing social and political issue, shaping electoral politics and contributing to the 1926 General Strike. It also coincided with major structural changes in the economy, as export-oriented heavy industries concentrated in the North of England, Scotland, and Wales were overtaken by expanding light manufacturing industries often located in the South of England.

The interwar British unemployment crisis is of academic interest not only because it was one of the largest employment downturns in the twentieth century, but because of its role in the development of macroeconomics. The prolonged period of high unemployment in Britain in the 1920s was the backdrop for, and in some ways was the impetus of, the development of John Maynard Keynes' *The General Theory of Employment, Interest, and Money* (1936). Alongside the development and debate surrounding Keynesian macroeconomics, economic research since the 1970s has taken up interwar British unemployment as a historical episode with which to explore the validity of Keynesian interpretations. A large debate in the literature has focused on the extent to which depressed aggregate demand (Broadberry 1983; Dimsdale, Nickell, and Horsewood 1989; Turner and Bowden 1997) or aggregate labor market rigidities such as inflexible wages, unemployment insurance, and trade unionization (Beenstock and Warburton 1986, 1991; Hatton 1988; Hatton and Thomas 2013) contributed to high levels of overall interwar unemployment.

By using new industry-level data and a novel empirical approach, this paper provides an alternative perspective on this debate, emphasizing job and worker reallocation across industries. The macroeconomic frameworks favored in the existing literature on interwar Britain have generally assumed that aggregate forces or shocks generated broadly similar outcomes throughout the workforce. They abstract away from the frictions and costs of reallocating jobs and workers across sectors, and thus have not dealt with the key issue of job and worker flows in the interwar British labor market. Owing to the absence of detailed data, no previous research has been able to establish the extent to which impediments to reallocation may have contributed to interwar unemployment or how adjustment to reallocative shocks may have varied by sector, region, and gender.

This paper takes up these open questions, investigating how much job reallocation occurred in interwar Britain and how cross-industry job finding rates varied for workers associated with different industries, from different geographic regions, and of different gender. The analysis is made possible by the digitization of rich government data on employment and unemployment in 100 industries, 1924 through 1936, from the Ministry of Labour *Gazette*. With this detailed data, I first provide new evidence of sectoral-level job creation and destruction rates, which indicate allocative shocks were significant in interwar Britain. I decompose these sectoral job changes into between- and within-sector effects, showing large changes in the industrial structure. Then, I explore whether labor markets were more flexible for some workers than others using two methods. First, I estimate job finding rates on the industry level, representing the extent to which workers were able to transition from one industry into another industry. Then, I estimate Markov transition probabilities between sectors, using these estimates in a simulation to connect impediments to reallocation to the persistence of workers' unemployment.

I estimate industry-level job finding rates by relating changes in employment in an industry to changes in unemployment in the same industry using least squares. This takes advantage of the fact that unemployed workers were associated with the industries in which they were last employed in the Ministry of Labour data. For industries with job destruction, I estimate the extent to which laid-off workers were able to find a job in a different industry rather than joining the pool of unemployed labor in their previous industry. For industries with job creation, I estimate whether workers were hired from the unemployed pool associated with that industry or if they came from other industries or from outside the labor force. This empirical framework allows estimates to be compared over time, across sectors, by gender, and by region.

Then, I model worker reallocation across sectors and employment states as a Markov process. Transition probabilities can be estimated from the proportions in aggregate states using conditional least squares (Lee, Judge, and Zellner 1970; MacRae 1977; Van Der Plas 1983; Kalbfleisch and Lawless 1984). For the period 1923–1936, I use data on the proportion of the labor force in twelve employment-sector states, representing employment and unemployment in six sectors. I estimate Markov transition probabilities between states as a quadratic programming problem and bootstrap standard errors using residual resampling. Then, I simulate 120,000 individuals in the Markov process to generate predicted paths for workers who were employed or unemployed in each industry. This generates estimates of the persistence of unemployment for individuals in each employment-sector state.

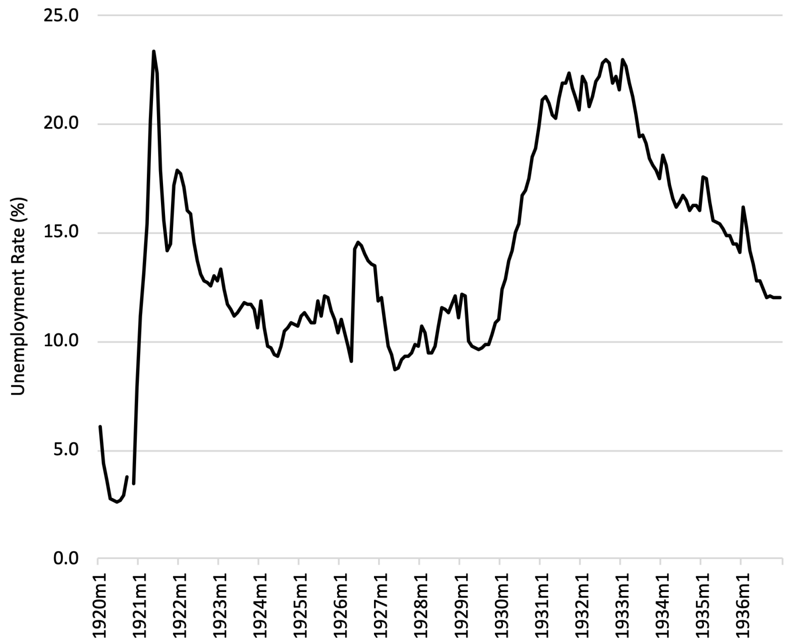
I find that some workers faced much greater impediments to reallocation than others, increasing their risk of persistent unemployment. Workers in textile and mining industries, those in the North of England and Wales, and women, relative to men, were less likely to find jobs in other industries and had a higher risk of long-term unemployment. In contrast, workers in services and in some types of manufacturing, those in the South East of England, and men were better off than has been previously thought by some scholars, with many labor market opportunities and a low risk of long-term unemployment. The Great Depression increased differences in labor market flexibility between these groups, accelerating the movement of workers into expanding industries while further limiting the options for workers in structurally disadvantaged industries. This is new econometric evidence that certain groups were disadvantaged in the interwar labor market — some workers faced not only a higher risk of becoming unemployed because of job destruction in their industry, but also a lower chance of finding a job in another industry.

Taken together, the results in this paper provide evidence for a new explanation of interwar unemployment focused on the reallocation of jobs and workers across industries and sectors. Previously, a favored interpretation was that the interwar labor market was sclerotic in aggregate, which either drove interwar unemployment from the supply side or played a role in amplifying a demand-side shock. The evidence in this paper suggests that interwar unemployment was in part spurred by allocative shocks that generated significant job creation in some industries and job destruction in others. Impediments to job and worker reallocation in the face of these shocks contributed to high unemployment, but, importantly, only some groups of workers were affected. Other workers faced relatively flexible labor markets and had high job finding rates. These unequal impacts appear to have been amplified by the business cycle, which widened the gap in adjustment between structurally-advantaged and disadvantaged industries and regions. This new perspective on a key historical employment downturn has implications for historical and modern monetary and fiscal policy.

1.1 Interwar unemployment

The inflationary boom at the end of World War I — driven by pent-up consumption, nominal wage increases, and working week decreases — collapsed into a global depression from 1921 to 1922. Figure 1 shows that this downturn was particularly severe in Britain, where the unemployment rate increased from an average of 3.9% in 1920 to over 20% in the spring of 1921, reaching a maximum for the decade of 23.4% in May of 1921. The war had shifted Britain's position in the world economy substantially — Britain was no longer at the nexus of global trade or the arbiter of the international gold standard. Policymaking was

Figure 1: Aggregate unemployment in Britain, 1920–1936



Source: National Bureau of Economic Research, Insured Workers Unemployed for United Kingdom [M082ABGBM513NNBR], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/M082ABGBM513NNBR.

clouded by the uncertainty of reparations, inter-Allied war debt repayments, and labor militancy.

By the middle of the 1920s, the economy had recovered by many measures. From the end of the war, Britain had pursued an objective of returning to the gold standard at its pre-war parity with the dollar. Tight monetary policies throughout the early 1920s helped Britain avoid the high inflation experienced by other European countries. The pound was restored to the gold standard in 1925, making London once again the center of the international money market. By 1924, the issue of Britain's debts to the US was also settled, and the Dawes Plan temporarily handled questions of German reparations. Despite this seeming restoration of normality, however, unemployment remained remarkably high, averaging over 10% in the late 1920s (Figure 1). The General Strike of 1926, motivated by the plight of coal miners, highlighted unemployment as an urgent social and political issue. By the 1929 General Election, remedies for unemployment were a key part of every major party's platform.

The worldwide Great Depression of the early 1930s exacerbated unemployment in Britain. The unemployment rate climbed to over 20%, where it remained for all of 1931 and 1932 (Figure 1). The gold standard prevented credit expansion by means of lower interest rates, as the Bank rate was effectively linked to the United States' discount rate. With over three million workers unemployed, Britain finally refused to increase the Bank rate any further to protect its gold reserves in September 1931, forcing the pound off the gold standard. Under a new system of flexible exchange rates, the Bank rate was reduced from 6% to 2% through June 1932. Long-term interest rates fell, driving a sustained boom in home construction from 1933. Eventually, rearmament spending led to a full recovery before the onset of World War II. In international comparison, unemployment was higher and more persistent in Britain than in the rest of Europe during the 1920s, but Britain recovered relatively quickly from the Great Depression after leaving the gold standard.

Throughout the interwar period, Britain experienced substantial shifts in its economic structure. At the end of World War I, it faced increased international competition in markets for its major pre-war exports. The war had interrupted the cotton trade with Asian countries, which responded by developing their own supply lines. Production of coal increased throughout Europe, displacing British firms that had built up the capacity to meet domestic and international demand in wartime. Domestic markets were shifting away from traditional products and toward alternative substitutes — relying on electricity, gas, and oil rather than coal, and preferring road transport to railways, for example. Many industries grew up closer to large consumer markets, establishing industrial hubs in the Midlands and in Greater London. Trends toward agglomerations and branched firms raised the barriers to entry in some industries. The industrial structure was also affected by tariffs, subsidies, and direct government intervention, especially in the 1930s.

The significance and severity of interwar unemployment led to a sustained interest in the downturn among economists and economic historians. Following the publication of Keynes's *General Theory* in 1936, interwar unemployment was typically assumed to have been Keynesian in nature (Beveridge 1944, pp. 90-109, for example). The contention of Benjamin and Kochin (1979) that interwar unemployment was voluntary, induced by generous unemployment benefits, cast doubt on this view. Though this paper was heavily criticized,[1] it generated interest in the role of supply factors in interwar unemployment. This led to a large debate in the literature on whether interwar unemployment was driven by aggregate demand fluctuations or systemic, institutional labor market rigidities such as inflexible wages, unemployment insurance, and trade unionization.

Much of this research focused specifically on whether high wages during the 1920s or early 1930s caused or contributed to the economic downturn. Beenstock and Warburton (1986, 1991) argue that the growth in real wages from 1929 to 1932, due in part to unemployment benefits, reduced labor demand and increased labor supply. Hatton (1988) finds that high real wages reduced employment during the Great Depression,

1. The *Journal of Political Economy* published a series of responses to Benjamin and Kochin (1979) in 1982 — see Collins (1982), Cross (1982), Metcalf, Nickell, and Floros (1982), and Ormerod and Worswick (1982). Additional criticisms are in Hatton (1983, 1985), and further exploration of the issue is given in Hatton and Bailey (2002) and Eichengreen (1987).

noting that other supply-side factors such as unemployment insurance and demographic changes could also have played a role. In a general equilibrium model, Cole and Ohanian (2002) argue that the incentive effects of unemployment benefits were in fact the key explanation for elevated unemployment levels in the interwar period. Hatton and Thomas (2013) emphasize the role of other institutional factors such as unions and centralized wage setting, and Luzardo-Luna (2020) finds additional evidence for aggregate labor market frictions in a search-and-matching framework. Lennard (2022), however, suggests that nominal wages may not have been as sticky as previously thought.

Other scholars have argued for the importance of demand-side effects. Dimsdale (1984) criticizes the focus on real wages, noting that the effects of wage increases in the 1920s were more significant than in the 1930s and that price changes need to be taken into account. Dimsdale, Nickell, and Horsewood (1989) find that the early 1930s recession was not instigated by real wage changes but rather by a large demand shock, with sticky prices and wages translating this demand shock into unemployment. Broadberry (1986) argues that supply-side factors were more important in the 1920s than in the early 1930s, with the fall in average hours worked and consequent rise in the real wage more important than unemployment benefits.[2] But, the experience of the early 1930s recession and then recovery he finds to be driven primarily by demand-side factors. This contrasts with the results in Crafts (1989), which, by incorporating long-term unemployment, suggest supply-side forces did contribute to high unemployment in the 1930s.

The present paper provides an alternative perspective on this debate by emphasizing job and worker reallocation across industries, relaxing the assumption that supply or demand shocks had homogenous impacts throughout the workforce. In doing so, this paper finds that impediments to worker reallocation in the face of allocative shocks contributed to high unemployment, but that some groups of workers were more affected by these rigidities than others.

This paper builds on literature criticizing the broad debates on interwar British unemployment for obscuring or ignoring significant regional and industrial patterns in unemployment (Booth and Glynn 1975, pp. 614-615; Gazeley and Rice 1996, p. 297; Luzardo-Luna 2022). Previous papers have considered variations in unemployment by industry but have been limited by a lack of comprehensive industry data, such as Gazeley and Rice (1992), Bowden, Higgins, and Price (2006), Turner and Bowden (1997), and Luzardo-Luna (2020) who consider unemployment in four, twenty-one, twenty-five, and fifteen industries, respectively. The present paper expands the Ministry of Labour data which is used in these prior papers

2. Broadberry (1990) gives more detail about the decrease in hours worked in the early 1920s. A fall in the price level because of deflationary government policy also contributed to an increase in the real wage in this period.

to capture, for the first time, all 100 industries. This paper can thus give a comprehensive view of the extent of structural reallocation in interwar Britain, enabling four times as many industries to be analyzed as in any previous study.

The emphasis on job and worker reallocation in this paper speaks to earlier research by historians that acknowledged the scale of structural change in interwar Britain as part of a larger debate on the impact of structural change on productivity. Some historians argued that the reallocation of labor from "old" to "new" industries contributed to strong economic growth and productivity gains in Britain during the interwar period (Aldcroft 1969a, 1969b; Richardson 1969; Dowie 1969, for example). The link between structural change, productivity, and growth has been criticized, however, in more recent work.[3] The present paper builds on this literature by providing new quantitative evidence on the influence of job and worker reallocation on interwar unemployment. Impediments to worker reallocation are found to have played a central role in the high level of interwar unemployment, though they generated different labor market experiences for different groups of workers.

2 Ministry of Labour *Gazette* Data

In 1911, Britain established the first national unemployment benefit scheme in the world. Originally available to about 2 million workers in volatile industries such as building and engineering, it was expanded at the end of World War I to cover over 11 million workers in most industries. The benefit scheme included all contract or apprenticeship workers aged 16 or over in manual work, as well as those earning less than £250 per year in non-manual work. It excluded a few industries — agriculture, domestic service, forestry, and horticulture — because of their low risk of unemployment,[4] as well as various civil service, military, and teaching jobs (Garside 1980, 31-32).

Data on the numbers employed and unemployed in 100 insured industries, disaggregated by gender, were generated by the operation and management of this National Insurance scheme. Unemployment statistics were collected and distributed in the monthly Ministry of Labour publication, the *Labour Gazette*. Each July, the number of people registered under the scheme was determined by the issue of Unemployment

3. See Von Tunzelmann (1982), Buxton (1975), and Broadberry (1983). More recent estimates of British economic growth and productivity during the interwar years are also less sanguine (Broadberry and Crafts 1992; Broadberry 1997; Mitchell, Solomou, and Weale 2012, for example).

4. HC Deb 23 February 1921 vol 138 c1060. Mr. Thompson says, "The reason why the right hon. Gentleman excluded two classes from the insured people, namely, domestic servants and agricultural workers, was that the unemployment in those two classes was so small that they need not come into a general scheme."

Books at local unemployment exchanges. Workers who could not find employment lodged their books at the exchange. Every month, the *Labour Gazette* unemployment rate was calculated as the total "Books Lodged" on a given day, divided by the total number of workers insured in July.[5] Separate figures were given for men and women across 100 industries.

This paper contributes the first complete digitization of this Ministry of Labour employment and unemployment data from 1923 to 1936. For 163 original Ministry of Labour *Gazettes*, representing every month over 14 years, June 1923 – December 1936,[6] I scanned the table "Unemployment in Insured Industries," which gives the number of unemployed for the month in 100 industries, disaggregated by gender. I then used optical character recognition (OCR) software to convert the images to editable text and cleaned and verified every row and column of the data. Linking the monthly files generated a time series of unemployment for men and women in 100 industries over the 1923–1936 period.[7] This unprecedented data allows for a new industry-level look at interwar unemployment, enabling a novel analysis of worker and job flows in interwar Britain.

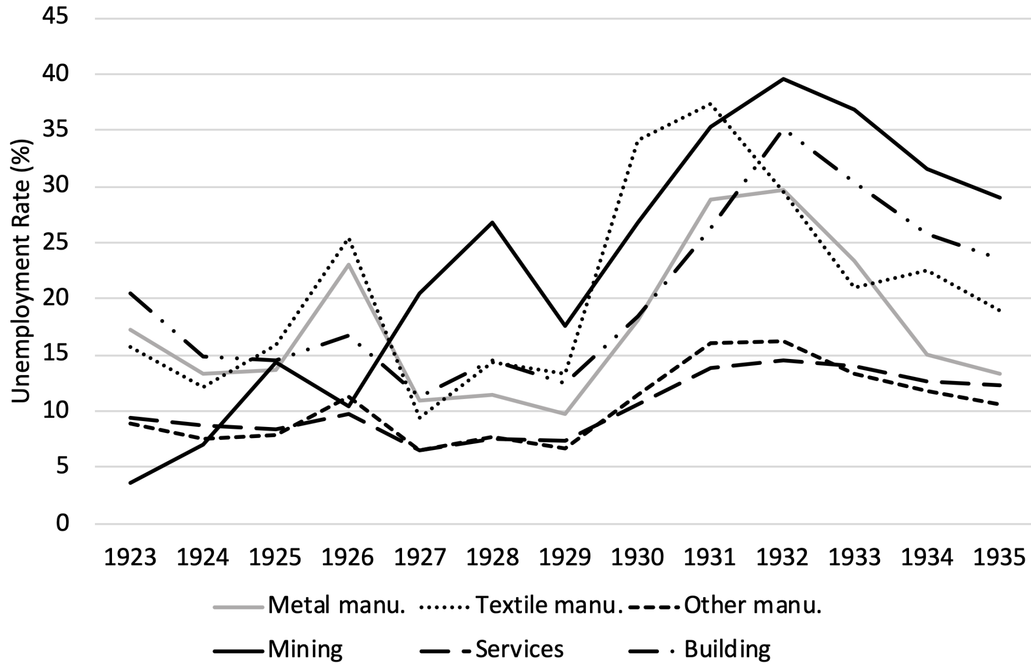
The detailed industry data from the *Labour Gazette* allow us to develop a complete picture of the change in industrial composition throughout interwar Britain for the first time. I categorize the 100 industries into six sectors based on a grouping provided in the raw Ministry of Labour data[8] These sectors are metal manufacturing, metal work, and engineering; textile manufacturing; other manufacturing (besides metals and textiles); mining and mining products; service and transport; and building and shipbuilding. Figure 2 gives the unemployment rate in July of each year for these six sectors. It is immediately apparent that the rich industrial unemployment information in this new dataset is important, as some sectors experienced much more unemployment than others. Unemployment rates were highest in mining, textile manufacturing, and metal manufacturing industries, and lowest in service and other manufacturing industries. The next section explores these trends in more detail.

3 Allocative shocks in interwar Britain

The macroeconomic focus of the existing economic literature on interwar British unemployment has presupposed that aggregate shocks had a largely homogenous effect throughout the workforce. This contrasts

5. Garside (1980, p. 55) details how this process was complicated somewhat by the Two Months file.
6. The *Labour Gazettes* referenced are held by the Bodleian Libraries, Oxford. Prior to June 1923, unemployment statistics are only available for 63 industries.
7. The central dataset developed for this paper includes both Great Britain and Northern Ireland.
8. For details, see the complete mapping of industries given in Appendix Table 10.

Figure 2: Unemployment rate by sector, 1923–1935



Analysis using employment and unemployment data from the Ministry of Labour *Gazette*, 1923–1935, for men and women together. The industries in each sector are given in Appendix Table 10. The unemployment rate is the average rate of all industries in each sector, weighted by the numbers insured in each industry.

with more recent models in labor economics concerned with the role of allocative shocks, which cause disperse, idiosyncratic variation in profitability or productivity across job sites or worker-job matches (Davis and Haltiwanger 1999; Mortensen and Pissarides 1994, for example). These allocative shocks generate job and worker reallocation, which can be impeded by search costs, moving costs, and other frictions. These impediments to reallocation may contribute directly to aggregate unemployment, or they may cause aggregate shocks to have heterogeneous impacts.

To what extent did allocative shocks affect interwar Britain? To answer this question, this section provides new evidence of sectoral-level job creation and destruction rates. We conceive of job creation at time t as the sum of all increases in employment for industries that expanded in employment between $t-1$ and t, and job destruction as the sum of all decreases in employment for industries that contracted in employment. Because there are no comprehensive firm-level data for interwar Britain, the analysis in this paper is at the industry level, and flows between firms and between establishments within a firm are both hidden. Our notion of allocative shocks is thus also at the industry level – allocative shocks may have caused idiosyncratic variation in profitability or productivity *between industries*, generating job and worker reallocation across industries that may have been impeded. While this is a departure from the literature on recent economies, it accords well with studies on interwar Britain, and contemporary analyses, that emphasized changes in the industrial structure.

While some definitions of job creation and destruction incorporate measures of short-term vacancies, vacancies are not as useful, conceptually or in operation, for interwar Britain owing to the general excess supply of labor. Hatton (1985) finds that any vacancies in interwar Britain were almost immediately filled, and certainly filled within a matter of months. He notes that the vacancies data available at local employment exchanges may in fact just be permanent notices from local employers to ensure they could continue to instantly fill any real vacancies which may have popped up in the future (Hatton 1985, pp. 268-269). We thus assume that the employment level of industries is the industries' ideal employment level, so expansions and contractions of employment can be thought of as changes in the industries' desired employment, owing to allocative shocks, rather than changes in their stock of vacancies.

3.1 Job creation, job destruction, and reallocation rates

Adapting Davis and Haltiwanger (1999), we can think of a sector s with industries i, and define the subset of s called S_t^+ as the set of industries i with expanding employment between $t-1$ and t. Define S_t^- as the set of industries i with contracting employment between $t-1$ and t.

Job creation in sector S, for expanding industries i at time t, is given

$$C_{st} = \sum_{i \in S^+} \Delta E_{ist},$$

where E_{ist} is employment in industry i in sector s at time t.

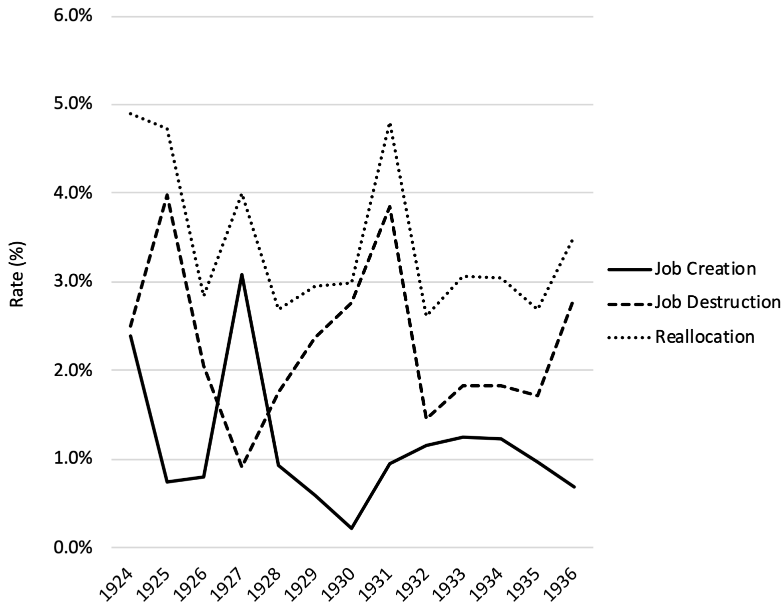
Job destruction in sector S, for expanding industries i at time t, is given similarly

$$D_{st} = \sum_{i \in S^-} |\Delta E_{ist}|.$$

These can be written as job creation and destruction rates by dividing by the average size of the sector in time t and $t-1$, which we can call Z_{st}. Then c_{st}, the job creation rate, is $\frac{C_{st}}{Z_{st}}$, and d_{st}, the job destruction rate, is $\frac{D_{st}}{Z_{st}}$. The reallocation rate r_{st} is simply the sum of the job creation rate and the job destruction rate.

Figure 3 gives the aggregate annual job creation, destruction, and reallocation rates for interwar Britain. As one would expect, job destruction rises with the unemployment rate (give in Figure 1) and job creation

Figure 3: Annual job creation and destruction rates, 1924–1936



Analysis using employment and unemployment data from the Ministry of Labour *Gazette*.

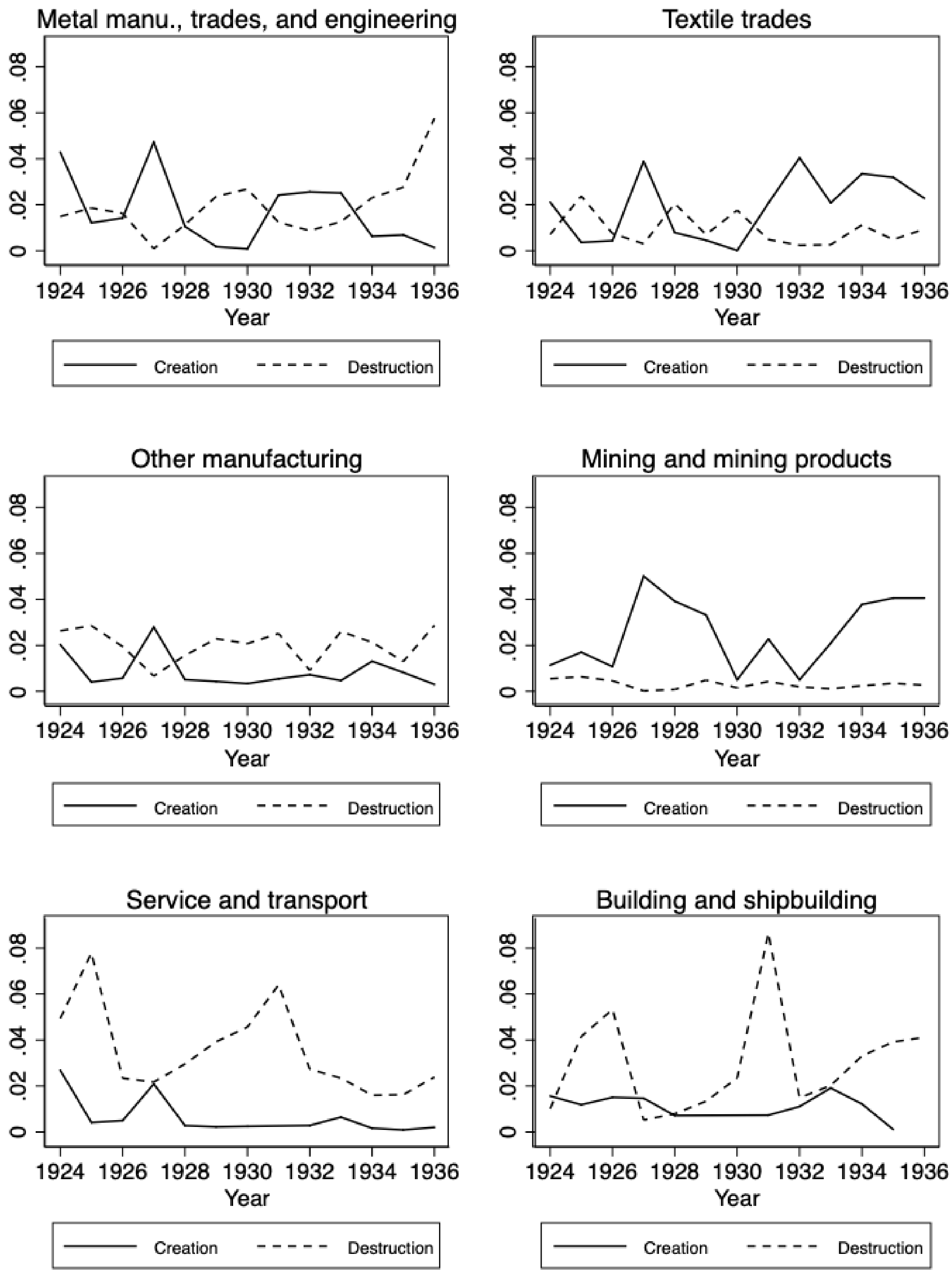
is the inverse. Job creation and destruction are swift during the interwar period, with job creation peaking at just over 3% of employment and job destruction peaking at 4%.[9] The average reallocation rate over the period is 3.5%.

Did job creation and destruction vary across sectors? The sectoral job creation and destruction rates given in Figure 4 indicate that some sectors experienced much more job destruction, and much less job creation, than others. Job creation and destruction in the metal manufacturing, metal trades, and engineering industries and in the textile industries closely maps the overall trends. Job creation is high in mining and mining products and relatively low in the service and building industries. Job destruction rates, in contrast, vary dramatically in the service and building industries, with pronounced peaks during the Great Depression years.

We can break down sectoral job reallocation rates into the part represented by net changes in employment in each sector and the part represented by reallocation between industries within a sector. To do this, we can take reallocation for a sector, R_s, and subtract the absolute value of the net employment change for the sector $|C_s - D_s|$. The remainder is reallocation between industries within the sector.

9. In modern labor markets, job creation and destruction are each about 10%, but these numbers are lower when estimated annually and when estimated for larger units (e.g. for firms rather than establishments) (Davis and Haltiwanger 1999). We thus expect our estimates to be much lower than 10% because our estimates are annual and on the industry level, rather than on the firm or establishment level, even before taking into account differences in information flows, technology, and dynamism between modern labor markets and the interwar labor market.

Figure 4: Sectoral job creation and destruction rates, 1924–1936



Analysis using employment and unemployment data from the Ministry of Labour *Gazette*.

Table 1 gives the results of this exercise. The average reallocation rate for each sector from 1924 to 1936 is given in the second column. The third column gives the percentage of reallocation that is owing to net changes in the employment level between sectors. The fourth column gives the percentage of the reallocation rate that is owing to simultaneous job creation and destruction among the industries comprising the sector. Reallocation in the metal manufacturing, metal trades, and engineering sector is primarily driven by reallocation among industries in the sector. In contrast, reallocation in mining is primarily owing to net changes in overall employment in the sector. Job reallocation across sectors and job reallocation between industries within sectors both contributed to high job reallocation rates in this period.

Table 1: Job Reallocation Rate Decomposed into Net Sectoral Employment Change and Within-Sector Reallocation

Sector	Avg. Reallocation Rate	% from Net Emp. Change Across Sectors	% from Industry Reallocation Within Sector
Metal manu., trades, and engineering	3.66%	8.20	91.80
Textile trades	2.85%	32.95	67.05
Other manufacturing	2.89%	40.98	59.02
Mining and mining products	2.85%	77.22	22.78
Service and transport	3.96%	46.01	53.99
Building and shipbuilding	3.91%	22.26	77.74

Analysis using employment and unemployment data from the Ministry of Labour *Gazette*, 1924–1936, for both men and women. The average reallocation rate is the average sum of the job creation and destruction rates for each sector given in Figure 4.

The high levels of job creation, job destruction, and job reallocation, as well as the varying patterns by sector, indicate that we should be concerned with the dispersed effects of allocative shocks in interwar Britain. This evidence indicates that large-scale job reallocation was occurring in interwar Britain, generating changes in the industrial structure. This suggests that allocative shocks may have played a significant role in interwar unemployment. If worker reallocation in response to these shocks was impeded by search costs and other frictions, this may have contributed to interwar unemployment.

4 Industry-level job finding rates

The evidence in the previous section indicates that allocative shocks were significant in interwar Britain. A large amount of worker reallocation across industries was thus required for market forces to restore full employment, and any impediments to that reallocation may have contributed to high levels of unemployment or caused heterogeneous impacts across industries, gender, or regions.

How much reallocation of workers across industries occurred before, during, and after the Great Depression? From which industries were unemployed workers able to find other employment opportunities? These questions motivate the two stages of the empirical analysis in this paper. In the first section of the analysis, job finding rates are estimated on the industry level, representing the extent to which workers were able to transition between industries. These job finding rates can be compared by sector, gender, region, and over time to explore whether interwar labor markets were more flexible for some workers than others. The second section of the analysis uses a Markov framework to estimate the probability of transitioning between employment or unemployment in six sectors. These estimates are used in a simulation to connect impediments to worker reallocation to the persistence of unemployment for workers from certain industries.

4.1 Model

The *Labour Gazette* associated unemployed workers with industries, offering a unique view into the total labor force, employed and unemployed, of industries during the interwar period.[10] Every worker in an insured industry was issued an Unemployment Book in July of each year, where the employee's and the employer's contributions to the tripartite unemployment program were recorded. When a worker became unemployed, they lodged their Unemployment Book at a local employment exchange, where it remained until they found new employment and provided the book to their new employer. The number of books lodged for each industry was counted monthly, establishing the number of unemployed workers each month in every insured industry. For each industry, we thus have a count of the numbers employed in the industry (numbers insured less unemployed) and the number of unemployed workers who were previously associated with that industry.

The relative changes in the numbers employed and unemployed can offer some insight into the dynamics of entry into and out of employment and unemployment across industries. If employment was declining in an industry, a large increase in unemployment in that industry suggests that many laid-off workers could not find jobs in other industries. If employment was increasing in an industry, a large decrease in unemployment in that industry suggests that hired workers came from the unemployed pool of that

10. The number insured is only a proxy for the full population working or looking for work in an industry, as unemployed workers could search for jobs in other industries. However, as soon as they found work in another industry, their association would be switched to the new industry.

industry rather than from other industries.

These intuitions can be formalized into cross-industry job finding rates, representing the extent to which laid-off workers in an industry were able to reallocate to a different industry. We conceive of a competitive interwar labor market subject to a series of allocative shocks which had disparate effects across industries, causing expansion of employment in some industries and contraction of employment in other industries (job reallocation). We also assume that there was little incentive for unemployed workers to leave the labor force owing to the generous unemployment benefit program. A simple relation of the change in the numbers employed and unemployed in an industry can generate the cross-industry job finding rate, which indicates the extent of worker reallocation across industries for workers associated with a particular industry.

Decompose the employment change in industry i into the part represented by a change in unemployment in industry i, the part represented by net movement from other industries (cross-industry worker reallocation), and the part represented by net flows of labor force participation.

The change in employment in an industry i from time $t-1$ to t can thus be represented

$$\Delta E_i = -\Delta U_i + \sum_{\substack{1 \leq j \leq 100 \\ j \neq i}} M_{j,i} + P_i \tag{1}$$

where ΔE_i is the change in employment in industry i from $t-1$ to t and ΔU_i is the change in unemployment in industry i from $t-1$ to t. $M_{j,i}$ represents the net movement of workers between industry i and j between $t-1$ and t, with $M_{j,i}$ positive if there is a positive net movement from j into i. P_i represents the net flow between industry i and outside of the labor market, with P_i positive if there is a positive net flow into industry i from outside the labor market.

If ΔE_i is positive, i.e. employment is expanding, then we would expect unemployment in the industry to decrease, positive flows from other industries, and possibly new workers being drawn into the industry from outside the labor force through positive flows in P_i. If ΔE_i is negative, we would expect unemployment to increase, labor flows from i to other industries, and flows from i out of the labor force. In the context of the generous and largely non-contributory unemployment benefit system, there was little incentive for unemployed workers to leave the active labor force so we expect flows from i out of the labor force, P_i to be negligible.

The cross-industry job finding rate arises from simply rewriting this equation as shares of the change in employment in industry i. Dividing through Equation (1) through by ΔE_i, and setting P_i to 0, gives the shares

$$1 = \frac{-\Delta U_i}{\Delta E_i} + \frac{\sum_{\substack{1 \leq j \leq 100 \\ j \neq i}} M_{j,i}}{\Delta E_i} \tag{2}$$

The cross-industry job finding rate, f_i, is the term

$$f_i = \frac{\sum_{\substack{1 \leq j \leq 100 \\ j \neq i}} M_{j,i}}{\Delta E_i}$$

For an industry contracting in employment, the cross-industry job finding rate f_i is the rate at which laid-off workers were able to find jobs in other industries. This is given by the ratio of workers who were able to move into employment in one of the other 99 industries, $M_{j,i}$, to the total change in workers from the industry seeking work, ΔE_i. For an industry expanding in employment, the cross-industry job finding rate represents the extent to which employment increases in an industry were supplied by workers from other industries.

For a contracting industry, an estimate of the cross-industry job finding rate f_i near 0 indicates that most of the laid-off workers remained unemployed in that industry, with little flow of workers to employment in other industries. A higher cross-industry job finding rate, closer to 1, indicates that a larger proportion of the decrease in numbers employed was able to find employment in other industries. For an expanding industry, the cross-industry job finding rate f_i gives the proportion of the expansion of employment in an industry made of up workers from other industries. f_i near 0 for an expanding industry indicates that the expanding industry drew on workers from its own unemployment pool, while f_i near 1 indicates that the expansion was made up mainly of workers from outside the industry's own unemployment pool.

Equation 2 indicates that the cross-industry job finding rate can be estimated as

$$1 - \frac{-\Delta U_i}{\Delta E_i} = 1 + \beta = \frac{\sum_{\substack{1 \leq j \leq 100 \\ j \neq i}} M_{j,i}}{\Delta E_i} = f_i$$

where β is defined

$$\beta = \frac{\Delta U_i}{\Delta E_i}.$$

The cross-industry job finding rate f_i equals $1 + \beta$, where β is $\frac{\Delta U_i}{\Delta E_i}$ for industry i. We can thus estimate β from an ordinary least squares regression of ΔU_i on ΔE_i, transforming our coefficients by adding one to generate estimates of f_i.

4.2 Estimation

Our goal is to generate estimates of cross-industry job finding rates that can be compared over time, across sectors, by gender, and by region to understand the extent to which workers reallocated across jobs in interwar Britain. To do this, our base model estimates cross-industry job finding rates for three time periods: the period of high unemployment in Britain before the global Great Depression (1925–1929), the period during the global Great Depression (1930–1933), and the period of recovery (1934–1936).

Cross-industry job finding rates for these three time periods can be estimated using the following least-squares regression on industry-year level data:

$$y_{it} = \beta_0 + \beta_1 x_{it} \cdot p_1 + \beta_2 x_{it} \cdot p_2 + \beta_3 x_{it} \cdot p_3 + \tau_t + \alpha_i + \epsilon_{it} \tag{3}$$

where y_{it} is the change in unemployment in industry i from period $t-1$ to t and x_{it} is the change in employment in industry i from period $t-1$ to t. p_1 indicates the first time period, 1925–1929; p_2 indicates the second time period, 1930–1933; and p_3 indicates the third time period, 1934–1936. α_i are industry fixed effects and τ_t are year fixed effects. For ease of interpretation, the regression is a partial interaction between x_{it} and p, with no main effect for x_{it} but main effects for each time period captured by the year fixed effects. The cross-industry job finding rate for the period 1925–1929 is thus given $f_{i,p_1} = 1 + \beta_1$; for 1930–1933 is given $f_{i,p_2} = 1 + \beta_2$; and for 1934–1936 is $f_{i,p_3} = 1 + \beta_3$.

In addition to the base model for the whole labor market, Equation (3) is also estimated for different subsamples of the data to allow comparisons over time by gender, sector, and region. Cross-industry job finding rates are estimated for each of six sectors including metal manufacturing, textile manufacturing, other manufacturing, mining, service, and building and for expanding and contracting industries, all for the overall labor force as well as for men only and for women only.

Then, an additional analysis is conducted where job finding window is expanded by one, two, or three years. In these models, the time period interaction is removed to allow for ease of interpretation. The resulting model is,

$$y_{it} = \beta_0 + \beta x_{it} + \tau_t + \alpha_i + \epsilon_{it}, \tag{4}$$

where y_{it} is the change in unemployment from $t-1$ to t, and x_{it} is the change in employment from $t-k$ to t with $k \in [1, 4]$. This equation is again estimated for different industry groupings and for men and women separately.

Finally, to estimate differences in the level of labor market adjustment across regions, cross-industry job finding rates are estimated for each industry individually for the full time period as well as for 1925–1929, 1930–1933, and 1934–1936. Then, the average cross-industry job finding rates for each region in England and Wales is computed using the distribution of workers across industries in each region from the 1931 *Census*. The cross-industry job finding rates for each industry are weighted by the industry's employment share in each region to generate a regional cross-industry job finding rate.

This analysis makes it possible to estimate the amount of worker reallocation across industries that occurred in interwar Britain for the first time and to consider variation in labor market flexibility for workers from different sectors, regions, and gender. However, it is important to keep in mind two limitations of this empirical approach. The first limitation is that these job finding rates are estimated on the industry level owing to the availability of employment and unemployment data for interwar Britain. We therefore cannot shed light on the specific rigidities that may have affected worker reallocation, including geographic factors, industrial organization, and the role of industry-specific human capital as one might be able to do with individual-level data. A second limitation is that we remain unable to distinguish flows across industries from flows into and out of the labor force. Though there was little incentive for insured workers to leave the labor force, expanding industries did draw new workers into the labor force. New entrants to the labor force are implicitly accounted for in the analysis, but it is impossible to tell from the cross-industry job finding rates for expanding industries the importance of new entrants relative to flows across industries.

4.3 Results

Table 2 presents the cross-industry job finding rate estimates for all industries and by sector for three time periods: 1925–1929, 1930–1933, and 1934–1936. Model (1) includes all 100 industries and models (2)–(7) only include industries in the listed sector. For example, the regression for textile manufacturing industries in (3) includes only the carpet manufacturing, cotton, hemp, hosiery, jute, lace, linen, silk, woolen and worsted, and textile bleaching and dyeing industries. The proportions of insured, employed, and unemployed men and women in each of the sectors are given in Appendix Table 11. Each model includes year and industry fixed effects.

The estimates represent the rate at which unemployed workers from one industry could transition into other industries, giving a sense of the flexibility and responsiveness of the labor market. An estimate near

0 signifies little to no labor flows across industries. In this case, changes in the number of unemployed in an industry were inversely proportionate to changes in that industry's employment. For a contracting industry, the entire decrease in employment is thus reflected in an increase in unemployment in that industry, suggesting that few laid-off workers moved to other industries. For an expanding industry, an estimate of 0 signifies that unemployment decreased proportionate to the increase in employment, suggesting that workers had been hired from the unemployment pool of that industry rather than from other industries.

In contrast, an estimate near 1 signifies substantial worker flows across industries and more labor market flexibility. For contracting industries, an estimate near 1 signifies that workers who were laid off were able to secure jobs in other industries rather than remaining unemployed in their previous industry. For expanding industries, this indicates that the industry increased their employment levels by drawing new workers rather than tapping into their existing unemployment pool.

Table 2: Cross-industry job finding rates for all industries and by industry category

	(1) Overall	(2) Metals	(3) Textiles	(4) Other Manu.	(5) Mining	(6) Service	(7) Building
1925-1929 × Δ Employed	0.20***	0.06***	-0.01***	0.34***	0.10***	0.89*	0.50**
	(0.02)	(0.04)	(0.03)	(0.03)	(0.02)	(0.04)	(0.15)
1930-1933 × Δ Employed	0.10***	0.03***	-0.14***	0.38***	-0.18***	1.26**	0.47***
	(0.02)	(0.04)	(0.03)	(0.05)	(0.04)	(0.09)	(0.07)
1934-1936 × Δ Employed	0.29***	0.51***	0.20***	0.56***	-0.51***	0.46***	0.64*
	(0.04)	(0.06)	(0.11)	(0.04)	(0.19)	(0.11)	(0.14)
Constant	3407.65***	544.78	2406.97	1183.39***	-366.65	2576.82	5839.13
	(656.37)	(887.08)	(1396.19)	(306.14)	(1460.07)	(1836.96)	(5577.28)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Num. of observations	1200	228	132	504	120	180	36
R2	0.798	0.904	0.968	0.727	0.976	0.520	0.933

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The entries are the coefficient estimates from the model described by Equation (3) plus one, where the dependent variable is the change in unemployment from $t-1$ to t in industry i and where "Δ Employed" is the change in employment from $t-1$ to t in industry i. The estimates represent whether a decrease (increase) in employment in an industry coincided with a proportionate increase (decrease) in unemployment in the industry. Estimates near 0 indicate little to no adjustment across industries, as the entire change in employment is reflected in the change in unemployment in that industry. Estimates near 1 indicate almost perfect adjustment across industries. Standard errors given in parentheses. Analysis using employment and unemployment data from the Ministry of Labour *Gazette*, 1924–1936, for both men and women.

Model (1), using all 100 industries, suggests that during the Great Depression, there were fewer worker flows across industries overall than in the period before or after. The cross-industry job finding rate decreased from 0.20 in the late 1920s to 0.10 during the Great Depression, and then rose again to 0.29 from 1934–1936. These estimates suggest that if an industry laid off 100 workers in a given year during the Great Depression, 90 of those workers would remain unemployed in that industry and 10 would find jobs in other industries. In the late 1920s, only 80 workers would remain unemployed in that industry, and during the recovery years 1934–1936, only 71 workers would remain unemployed.

These overall trends mask variation across sectors. The sectors with the highest job finding rates were services in model (6), building in model (7), and other manufacturing in model (4). In all three periods, the job finding rates of workers from these sectors were much higher than those for workers from the worst-performing sectors including textile manufacturing (3) and mining (5). For example, looking at the late 1920s period, the mining and mining products sector had a cross-industry job finding rate of 0.10, signifying very low worker flows across industries, whereas the service sector had a cross-industry job finding rate almost nine times higher, at 0.89.

The trend across time also varies by sector. The cross-industry job finding rates for mining and textiles decreased in the Great Depression years by 0.28 and 0.13, respectively, whereas, n constrast, the cross-industry job finding rates for the other manufacturing industries and for service industries actually increased. The cross-industry job finding rate for the service industries during the Great Depression is also remarkable for being greater than 1. While an estimate near 1 indicates substantial adjustment across industries, an estimate much greater than 1 suggests some amount of over-adjustment. For contracting service industries, this job finding rate greater than 1 suggests that as employment decreased, unemployment also decreased. Not only were laid-off workers not added to the unemployment pool for their industry, but previously unemployed workers were able to find employment in other industries. For the expanding industries in service, this implies that as employment increased, unemployment also increased. This could suggest new workers being drawn into the labor force as unemployed service workers.

During the recovery years, the cross-industry job finding rates recover for all of the manufacturing sectors and for building. In fact, for all of these sectors, worker reallocation was higher in the mid-1930s than in the late 1920s, especially in the metal manufacturing and building industries. However, it is remarkable that the job finding rate for mining workers continued to decline precipitously even during the recovery years. The job finding rate for the service industries also declined, possibly a correction of the overadjustment of the Great Depression years.

Table 3 suggests that worker reallocation was lower for female workers than for male workers on the whole during the late 1920s and during the Great Depression. The top panel presents the job finding rates overall and by industry category using only men's employment and unemployment in each industry, while the bottom panel uses only women's employment and unemployment. Surprisingly, for men across all industries in model (1), job finding rates only slightly decreased during the Great Depression, from 0.18 in the late 1920s to 0.16. In contrast, for women in model (8), job finding rates declined significantly during the Great Depression, from 0.12 to −0.12. This was driven by the exceptionally poor performance of the textile industries for women (10), whose job finding rate declined five times more than the job finding rate for men in those industries (3).

Table 3: Cross-industry job finding rates by gender for all industries and by industry category

Men	(1) Overall	(2) Metals	(3) Textiles	(4) Other Manu.	(5) Mining	(6) Service	(7) Building
1925-1929 × Δ Employed	0.18***	0.03***	0.04***	0.52***	0.10***	0.80***	0.50**
	(0.02)	(0.03)	(0.04)	(0.04)	(0.02)	(0.05)	(0.15)
1930-1933 × Δ Employed	0.16***	0.00***	0.00***	0.34***	-0.18***	1.13	0.47***
	(0.02)	(0.04)	(0.04)	(0.04)	(0.04)	(0.09)	(0.08)
1934-1936 × Δ Employed	0.32***	0.49***	0.25***	0.58***	-0.51***	0.36***	0.65*
	(0.04)	(0.06)	(0.14)	(0.03)	(0.19)	(0.11)	(0.14)
Constant	2176.41***	-323.31	982.68	393.96	-406.27	2916.55*	5871.28
	(517.75)	(792.56)	(644.59)	(227.20)	(1447.41)	(1412.56)	(5613.99)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.814	0.917	0.937	0.698	0.977	0.547	0.932
Women	(8) Overall	(9) Metals	(10) Textiles	(11) Other Manu.	(12) Mining	(13) Service	(14) Building
1925-1929 × Δ Employed	0.12***	0.76**	-0.02***	0.20***	1.02	1.04	0.97
	(0.02)	(0.08)	(0.03)	(0.03)	(0.09)	(0.06)	(0.07)
1930-1933 × Δ Employed	-0.12***	0.16***	-0.22***	0.49***	0.81	1.47***	0.98
	(0.02)	(0.07)	(0.03)	(0.05)	(0.18)	(0.10)	(0.14)
1934-1936 × Δ Employed	0.43***	0.78**	0.24***	0.75***	0.84	1.08	1.00
	(0.05)	(0.07)	(0.11)	(0.06)	(0.21)	(0.12)	(0.11)
Constant	1310.50***	185.78	1403.77	717.18***	36.82	-99.52	34.62
	(242.53)	(201.07)	(872.68)	(145.45)	(38.72)	(755.06)	(48.66)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.825	0.603	0.973	0.690	0.185	0.301	0.616
Num. of observations	1200	228	132	504	120	180	36

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The entries are the coefficient estimates for the model described by Equation (3) plus one, where the dependent variable is the change in unemployment from $t-1$ to t in industry i and where "Δ Employed" is the change in employment from $t-1$ to t in industry i. The estimates represent whether a decrease (increase) in employment in an industry coincided with a proportionate increase (decrease) in unemployment in the industry. Estimates near 0 indicate little to no adjustment across industries, as the entire change in employment is reflected in the change in unemployment in that industry. Estimates near 1 indicate almost perfect adjustment across industries. The top panel uses counts of employed and unemployed for men only, and the bottom panel uses counts of employed and unemployed for men only. Standard errors given in parentheses. Analysis using gender-disaggregated employment and unemployment data from the Ministry of Labour *Gazette*, 1924–1936.

Another departure between men and women is in other manufacturing industries. In the late 1920s, the cross-industry job finding rate for women in these industries (11) was lower than for men (4). However, during the Great Depression, the job finding rate decreased for men in these industries and increased for women. The job finding rate continued increasing for women to a remarkable level of 0.75 during the

1934–1936 period.

Finally, both men and women from the service industries had increased job finding rates during the Great Depression, though job finding rates were generally higher for women in these industries than for men.

The cross-industry job finding rate has a slightly different interpretation for expanding and contracting industries, representing whether workers were drawn into the industry from other industries or whether workers were able to exit the industry to other industries. Table 4 groups industries by whether they were expanding in employment or contracting, with models (1)–(2) representing overall employment and models (3)–(6) disaggregating by gender.[11]

In general, workers from expanding industries had much higher cross-industry job finding rates than those from contracting industries. When both men and women are taken together, the job finding rates for workers from expanding industries (2) range from 0.55 to 0.76, whereas the job finding rates for workers from contracting industries (1) range from 0.06 to 0.56. This suggests that workers in contracting industries faced not only decreasing employment but also more impediments in their adjustment to these employment changes. Entry into an expanding industry was thus easier than exiting from a contracting industry's labor force.

The Great Depression served to widen the gap between expanding and contracting industries, decreasing job finding rates for workers from contracting industries and increasing job finding for expanding industries. During the Great Depression, the job finding rate for contracting industries fell by 0.17 while it increased for expanding industries by 0.19. The difference in the cross-industry job finding rates between contracting and expanding industries in models (1) and (2) was thus largest during the Great Depression.

This widening gap is echoed in the data for men's employment and unemployment (3, 4), but not for women (5, 6). Contracting industries had extremely low levels of worker flows across industries for women in the late 1920s, and this did not change much during the Great Depression. Expanding industries had better adjustment during the early 1920s, but, contrary to the overall trend, the job finding rate for women from expanding industries actually decreased during the Great Depression.

During the recovery, the overall estimates and the estimates for men suggest that job finding rates were

11. In Table 4 Columns (3)-(6) whether industries were expanding or contracting is determined separately for men and women. The results when expanding and contracting industries are defined based on their overall employment performance are given in Appendix Table 12. Job finding rates for expanding and contracting industries within each of the six industry categories are given in Appendix Table 13.

increasing for contracting industries and decreasing for expanding industries. Workers from contracting industries were thus better able to find jobs in other industries during the recovery, but expanding industries were relying more on their existing labor supply for their growing employment needs. Job finding rates increased for women in all industries during the recovery.

Table 4: Cross-industry job finding rates by gender for expanding or contracting industries

	Men and Women		Men Only		Women Only	
	Contracting (1)	Expanding (2)	Contracting (3)	Expanding (4)	Contracting (5)	Expanding (6)
1925-1929 × Δ Employed	0.11^{***}	0.57^{***}	0.19^{***}	0.51^{***}	-0.23^{***}	0.33^{***}
	(0.02)	(0.03)	(0.02)	(0.03)	(0.02)	(0.03)
1930-1933 × Δ Employed	-0.06^{***}	0.76^{***}	0.03^{***}	0.73^{***}	-0.25^{***}	0.24^{***}
	(0.02)	(0.05)	(0.02)	(0.05)	(0.02)	(0.06)
1934-1936 × Δ Employed	0.56^{**}	0.55^{***}	1.18	0.58^{***}	0.22^{***}	0.37^{***}
	(0.13)	(0.05)	(0.27)	(0.04)	(0.06)	(0.09)
Constant	-365.54	2244.58^{*}	-442.21	1786.51^{*}	-432.60^{*}	1361.10^{***}
	(658.33)	(872.86)	(524.22)	(720.83)	(216.57)	(307.83)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Num. of observations	483	717	505	695	490	710
R2	0.907	0.386	0.886	0.376	0.957	0.494

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The entries are the coefficient estimates for the model described by Equation (3) plus one, where the dependent variable is the change in unemployment from $t-1$ to t in industry i and where "Δ Employed" is the change in employment from $t-1$ to t in industry i. The estimates represent whether a decrease (increase) in employment in an industry coincided with a proportionate increase (decrease) in unemployment in the industry. Estimates near 0 indicate little to no adjustment across industries, as the entire change in employment is reflected in the change in unemployment in that industry. Estimates near 1 indicate almost perfect adjustment across industries. Contracting industries are those that had a decrease in employment from $t-1$ to t, while expanding industries had an increase. For the gendered analysis, whether an industry is contracting or expanding is defined within the gender. Standard errors given in parentheses. Analysis using gender-disaggregated employment and unemployment data from the Ministry of Labour *Gazette*, 1924–1936.

The previous tables have looked at how employment changes relate to unemployment changes within the same year. Table 5 explores different adjustment windows, giving a sense of how the speed of adjustment varied by gender and by industry category.

Each entry in the table is the coefficient plus one (cross-industry job finding rate) and standard error from a regression model where the dependent variable is the change in unemployment from $t-1$ to t and the independent variable is the change in employment from $t-k$ to t, where $k \in [1,4]$. The cross-industry job finding rates thus indicate how the changes in employment over the last $k-1$ years affect the change in unemployment in a year.

The estimates for men and women in Table 5 indicate that the effects of employment shocks on the size of the unemployed pool are felt most strongly in the same year and in the year afterward, with the impact on the unemployment pool diminishing, meaning the estimates go toward one, as the adjustment window widens. For women, the effects are generally slower than for men. By sector, adjustment happened quickest in building and metal manufacturing and slowest in mining.

Table 5: Speed of adjustment by gender and industry category

Overall and by gender	(1) Contemporaneous $k = 1$	(2) One Year $k = 2$	(3) Two Years $k = 3$	(4) Three Years $k = 4$
Men and Women: Δ Employed, $t-k$ to t	0.18***	0.64***	0.81***	0.84***
	(0.01)	(0.02)	(0.02)	(0.02)
Men Only: Δ Employed, $t-k$ to t	0.19***	0.64***	0.82***	0.81***
	(0.01)	(0.02)	(0.02)	(0.02)
Women Only: Δ Employed, $t-k$ to t	0.03***	0.55***	0.72***	0.96
	(0.02)	(0.03)	(0.02)	(0.03)
By industry category				
Metals: Δ Employed, $t-k$ to t	0.15***	0.69***	0.82***	0.94
	(0.03)	(0.04)	(0.03)	(0.04)
Textiles: Δ Employed, $t-k$ to t	-0.07***	0.48***	0.63***	0.85
	(0.02)	(0.09)	(0.07)	(0.11)
Other Manu.: Δ Employed, $t-k$ to t	0.42***	0.82***	0.88***	0.94**
	(0.02)	(0.03)	(0.02)	(0.02)
Mining: Δ Employed, $t-k$ to t	0.04***	0.54***	0.80**	0.65***
	(0.02)	(0.06)	(0.07)	(0.06)
Service: Δ Employed, $t-k$ to t	0.90*	1.03	1.10	1.22***
	(0.05)	(0.07)	(0.06)	(0.06)
Building: Δ Employed, $t-k$ to t	0.50***	0.83*	0.88	0.92
	(0.06)	(0.08)	(0.07)	(0.07)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The entries are the coefficient estimates for the model described by Equation (4) plus one, where the dependent variable is the change in unemployment from $t-1$ to t in industry i and where "Δ Employed" is the change in employment from $t-k$ to t in industry i. The estimates represent whether a decrease (increase) in employment in an industry coincided with a proportionate increase (decrease) in unemployment in the industry. Estimates near 0 indicate little to no adjustment across industries, as the entire change in employment is reflected in the change in unemployment in that industry. Estimates near 1 indicate almost perfect adjustment across industries. Analysis using gender-disaggregated employment and unemployment data from the Ministry of Labour *Gazette*, 1924–1936.

Finally, cross-industry job finding rates can be estimated for all 100 industries individually for 1925–1936 and for the three time periods 1925–1929, 1930–1933, and 1934–1936. Then, using the distribution of industries across twelve regions of England and Wales from the *Census of England and Wales* (1931), the average cross-industry job finding rate for each region can be calculated. The job finding rates of all of the industries are weighted by the proportion of workers in that industry in each region in 1931.[12] Because these estimates are based solely on the composition of industries in regions, they likely underestimate the difference in worker reallocation between regions since any regional effects outside of industrial composition are not considered.

The results are given in Table 6 and as a heat map in Figure 5, where a darker shade indicates a higher job finding rate. The South East and London regions had the highest estimated job finding rates, with the South West and the East regions following close behind. In contrast, areas of the North of England

12. As a robustness check, the analysis is conducted with the proportion of workers in each region in 1921 as well. These results are presented in Appendix Table 14.

Table 6: Estimated average cross-industry job finding rates by region

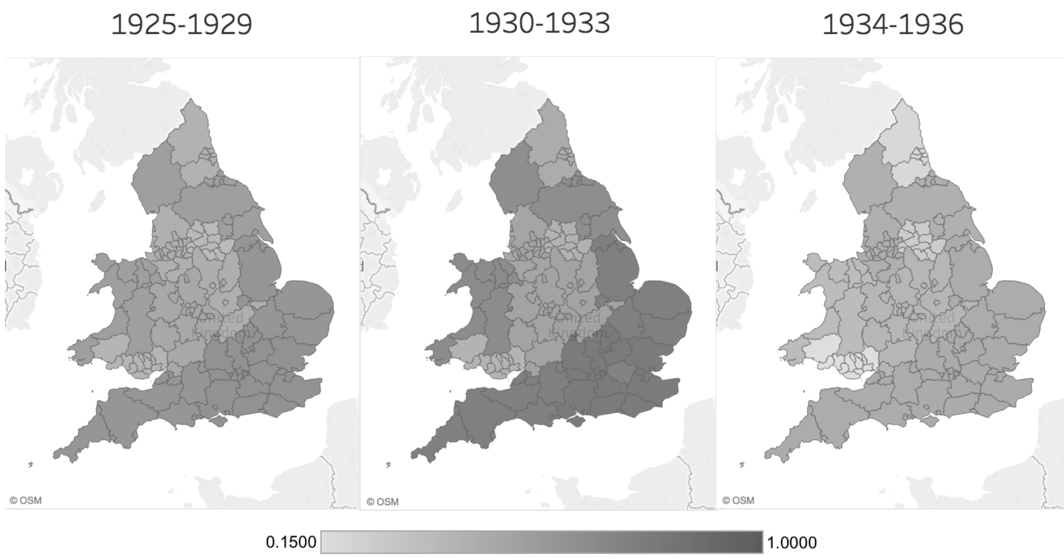
	Overall	By Time Period		
	1925-1936	1925-1929	1930-1933	1934-1936
South East	0.71	0.73	0.94	0.56
Greater London	0.68	0.71	0.85	0.56
South West	0.68	0.69	0.88	0.55
East	0.66	0.66	0.86	0.54
North 2	0.61	0.62	0.76	0.52
Wales 2	0.60	0.62	0.78	0.44
Midland 1	0.53	0.55	0.59	0.48
Midland 2	0.51	0.51	0.57	0.53
North 4	0.48	0.50	0.57	0.52
North 1	0.46	0.48	0.53	0.24
Wales 1	0.44	0.45	0.47	0.19
North 3	0.41	0.42	0.48	0.32

The entries are the average cross-industry job finding rates of industry-level coefficient estimates for the model described by Equation (4) plus one. For each region, the job finding rate of every industry is averaged, weighted by the proportion of the labor force, employed and unemployed, in that industry according to the 1931 *Census of England and Wales* Industry Report Table C. The estimates represent whether a decrease (increase) in employment in an industry coincided with a proportionate increase (decrease) in unemployment in the industry. Estimates near 0 indicate little to no adjustment across industries, as the entire change in employment is reflected in the change in unemployment in that industry. Estimates near 1 indicate almost perfect adjustment across industries.

and Wales had the lowest job finding rates, especially the south of Wales, Yorkshire, and Durham regions. During the Great Depression, job finding rates increased dramatically for the South East, London, and the South West — the areas that already had higher levels of cross-industry worker flows — widening the gap in job finding rates between the North and the South of Britain.

The results of this analysis suggest that adjustment to reallocative shocks varied significantly by sector, gender, and region. Workers who were associated with textiles and mining had the lowest cross-industry job finding rates, suggesting they could not find opportunities in other industries, while workers associated with service and other manufacturing industries had the highest job finding rates. When these results are disaggregated by gender, it is apparent that on the whole women faced less flexible labor markets than men, but there were variations in this pattern by industry. Job finding rates were higher for workers associated with industries that were expanding than for those associated with contracting industries, and for those in the South East and London regions rather than in the North and Wales. The effect of the Great Depression was to widen the gap in job finding rates between expanding and contracting industries and between the North and South of England. These results suggest that while some groups of workers faced significant impediments to transitioning into different industries, other groups of workers benefited from flexible labor markets and relatively easy access to alternative labor market opportunities, with the business cycle amplifying these differences.

Figure 5: Heat map of regional average cross-industry job finding rates over time



Regional cross-industry job finding rates as given in Table 6. A darker shade indicates a higher job finding rate, while a lighter shade indicates a lower job finding rate.

5 The persistence of unemployment

The interwar British labor market was subject to allocative shocks that necessitated worker reallocation across industries. The extent to which workers transitioned between industries varied significantly by the sector with which the worker was associated, their gender, and the worker's geographic region of employment. How did these impediments to worker reallocation affect interwar unemployment? This section models worker reallocation across sectors and employment states as a Markov process, estimating transition probabilities between sectors by gender. Using these estimates in a simulation, this section then explores the persistence of unemployment for workers from each sector.

5.1 Empirical strategy

There are no individual-level data available for the interwar period on the transitions of workers across industries, across sectors, or between employment and unemployment. Research on this period has instead focused on the aggregate data that can be readily observed from the Ministry of Labour *Gazette*, which is expanded for this paper. However, even when individuals' labor market transitions are not observed, it is possible to estimate mobility across sectors and employment states by modeling these transitions as a Markov process.

There is a large literature on estimating Markov transition probabilities from aggregate macro-level data (Lee, Judge, and Zellner 1970; MacRae 1977; Van Der Plas 1983; Kalbfleisch and Lawless 1984). In this literature, transition probabilities are estimated from the counts or proportions of individuals or other micro components in aggregate states using some form of conditional least squares. Recent work on collective graphical models in machine learning, where individual observations are generated by a graph but only contingency tables are observed, is analogous to this problem (Bernstein and Sheldon 2016). The method described in MacRae (1977) has been used recently to estimate time-homogenous transition probabilities between credit classes of mortgages (Walshe 2016) and to estimate transition probabilities between credit ratings of commercial bank loans (Jones 2005).

A transition matrix based on a time-homogeneous discrete Markov chain can be used to describe labor market mobility across sectors and between employment and unemployment. The Markov model has a number of states, S, representing employment status and sector pairs. At any point in time, all labor market participants can be classified into one of these employment-sector states, indicating their employment or unemployment in a specific sector. The transition matrix P describes the probability of remaining in the current state or transitioning to a different state in one time step. Each element of P, p_{ij}, gives the probability of transitioning from state i to j from $t-1$ to t. P is thus:

$$P[i,j] = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1S} \\ p_{21} & p_{22} & \cdots & p_{2S} \\ \vdots & \vdots & \ddots & \vdots \\ p_{S1} & p_{S2} & \cdots & p_{SS} \end{bmatrix}$$

The Markov process is assumed to be first-order stationary, so the individual probabilities p_{ij} do not change over time. It is also assumed that an individual's state at time t is exclusively affected by their state at time $t-1$. If x_t represents the state of an individual at time t, then this means $p_{ij} = Pr(x_t = j|x_{t-1} = i) = Pr(x_t = j|x_{t-1} = i, x_0, \ldots, x_{t-2})$.

With complete data on individual transitions, p_{ij} is simply the total number of people who moved from state i to state j between time $t-1$ and time t, divided by the total number of people who were in state i at time $t-1$. Letting $M_{i,j}$ represent the number of people who moved from state i to j, then:

$$p_{ij} = \frac{M_{i,j}}{\sum_{j=1}^{S} M_{i,j}}$$

In the interwar case, we do not have data on individual industry or employment status transitions. Instead, we are restricted to aggregate data on the proportion of workers in each sector and employment status pair. Using the same framework as in the full information case, following MacRae (1977), the aggregate proportions data can be used to estimate p_{ij} for all j and i with some error. As Appendix A describes, this amounts to setting up and solving a quadratic programming problem minimizing the sum of squared residuals subject to the constraints that each estimated $p_{ij} \in [0, 1]$ and that the rows of P sum to one.

Two additional constraints that derive from the specific context of the interwar unemployment system are added to the quadratic programming problem. Recall that the number unemployed in each industry was determined from a count of the number of insured workers who had lodged their Unemployment Books at local employment exchanges. The industry with which an unemployed worker was associated in the official employment figures was thus fixed until that individual secured employment in a different industry, removing their Unemployment Book from the exchange. This means that workers were nominally unable to move from unemployment in one industry to unemployment in another industry without first gaining employment. Additionally, they were unable to move from employment in one industry to unemployment in a different industry without first gaining employment in the latter industry. I add these two additional constraints to the model so that the only estimated transitions are those from unemployment in any sector to employment in any sector, from employment in one sector to employment in any other sector, and from employment in one sector to unemployment in the same sector.

For the period 1923 to 1936, I estimate this model with twelve employment-sector states, representing employment and unemployment in the same six sectors used throughout the paper. The analysis is conducted separately for men and women. Projecting the estimated probabilities forward suggests that the models fit the data well. A simulation of 120,000 individuals in each Markov process is then conducted to shed light on the persistence of unemployment for every employment-sector state.

This empirical strategy connects the impediments to worker reallocation identified in Section 4 with the persistence of unemployment. The Markov framework makes it possible to estimate which industries workers may have transitioned between, and how this affected long-term unemployment, without the need for individual-level data on worker transitions. However, the two assumptions of the Markov process are important limitations of this analysis to keep in mind. The assumption that the process is first-order stationary is necessary because of the limited availability of interwar data, but it likely does not match the true experience of interwar labor reallocation. The Markov condition that the process is memoryless again may not model true labor markets, where the exit rate from unemployment often exhibits negative duration dependence, i.e., where employment prospects are worse for those who have been unemployed longer (see Kroft, Lange, and Notowidigdo 2013). An additional limitation is that the analysis is conducted at the annual sector level, so transitions between industries within a sector are not captured.

5.2 Results

Tables 7 and 8 give the first statistical estimates of transitions across sectors and between employment and unemployment in the interwar British labor market. The transition probability estimates for men are given in Table 7, and the estimates for women are given in Table 8.[13] The entries in the table are the probabilities of moving from the employment-sector state on the row to the employment-sector state on the column. The diagonals give the probability of remaining in the same state. The italicized numbers are bootstrapped standard errors using the residual resampling method.

The results offer some insight into which industries workers could transition between during the interwar period. For example, the first row of the results for men in Table 7 indicates that unemployed men in metal manufacturing had a 56.6% chance of remaining unemployed, a 17.1% chance of finding employment in textile manufacturing, a 12.1% chance of finding employment in a service industry, and a 14.2% chance of finding employment in other manufacturing industries. In contrast, unemployed men in the textile industries had an estimated 67.4% chance of remaining unemployed and a 32.6% chance of finding employment in the building industries. As the estimates are based on movement in the aggregate proportion of workers in each employment-sector state, many transition estimates are zero. This does not indicate that no workers transitioned between these sectors, but rather that the aggregate data did not capture those transitions in trends of the two industries over the time period. The bootstrapped standard errors reflect this uncertainty.

The results for men in Table 7 suggest that unemployed workers in mining were most likely to remain unemployed (79.3%) while those in metal manufacturing were least likely to remain unemployed (56.6%). While unemployed metal manufacturing workers transitioned to textile, service, and other manufacturing industries, unemployed miners relied on transitions to the building industries.

13. These estimates for both women and men derive from the number of workers in each state, rather than from household-level data. We are thus unable to consider the interaction of employment patterns for men and women or to explore the possible role of women as a reserve supply of labor for the household.

Employment in the service industries for men was most secure. Workers in service industries had an 84.3% chance of remaining employed, a 9.0% chance of transitioning to building, a 2.4% chance of transitioning to other manufacturing, and a 4.3% chance of becoming unemployed. In contrast, metal manufacturing workers had a 9.0% chance of becoming unemployed, though the results for unemployment in metal manufacturing suggest they would not be unemployed for long.

For women, the estimates in Table 8 indicate that unemployed textile workers had a 49.4% chance of remaining unemployed, a 16.8% chance of regaining work in textiles, and a good chance of finding work in every other industry category. In contrast, unemployed service workers were much more likely to remain unemployed, at 64.5%, or otherwise were likely to be rehired in the service industries (31.9%).

Women in the service industries, however, were much less likely to become unemployed in the first place (2.3%) than female textile workers (12.5%). Female workers in the service industries had an 88.0% chance of remaining employed, a 6.3% chance of transitioning to other manufacturing industries, and a small chance of transitioning to metal manufacturing.

Table 7: Markov transition probabilities across employment-sector states, men only

	Unemployment						Employment					
	Metals	Textiles	Other Manu.	Mining	Service	Building	Metals	Textiles	Other Manu.	Mining	Service	Building
Unemp. - Metals	0.5662						0.0000	0.1707	0.1417	0.0000	0.1214	0.0000
	0.138						*0.093*	*0.090*	*0.136*	*0.059*	*0.129*	*0.144*
Unemp. - Textiles		0.6741					0.0000	0.0000	0.0000	0.0000	0.0000	0.3259
		0.268					*0.095*	*0.143*	*0.168*	*0.082*	*0.208*	*0.183*
Unemp. - Other Manu.			0.6936				0.0000	0.0000	0.0000	0.0000	0.3064	0.0000
			0.202				*0.074*	*0.049*	*0.150*	*0.020*	*0.179*	*0.150*
Unemp. - Mining				0.7931			0.0000	0.0000	0.0000	0.0000	0.0000	0.2069
				0.088			*0.052*	*0.036*	*0.071*	*0.023*	*0.093*	*0.087*
Unemp. - Service					0.7390		0.2334	0.0000	0.0000	0.0000	0.0292	0.0000
					0.152		*0.073*	*0.047*	*0.128*	*0.028*	*0.138*	*0.108*
Unemp. - Building						0.7448	0.0006	0.0000	0.2102	0.0444	0.0000	0.0000
						0.134	*0.099*	*0.061*	*0.126*	*0.044*	*0.104*	*0.091*
Emp. - Metals	0.0896						0.3513	0.2298	0.1117	0.0754	0.0389	0.1033
	0.035						*0.231*	*0.107*	*0.206*	*0.091*	*0.089*	*0.149*
Emp. - Textiles		0.0743					0.6876	0.0000	0.0009	0.2371	0.0000	0.0000
		0.070					*0.323*	*0.209*	*0.228*	*0.250*	*0.112*	*0.117*
Emp. - Other Manu.			0.0382				0.0999	0.0000	0.8239	0.0000	0.0380	0.0000
			0.027				*0.147*	*0.038*	*0.211*	*0.022*	*0.114*	*0.155*
Emp. - Mining				0.0709			0.0735	0.0820	0.0213	0.7524	0.0000	0.0000
				0.027			*0.068*	*0.070*	*0.051*	*0.084*	*0.021*	*0.041*
Emp. - Service					0.0429		0.0000	0.0000	0.0244	0.0000	0.8428	0.0899
					0.023		*0.031*	*0.012*	*0.077*	*0.005*	*0.111*	*0.102*
Emp. - Building						0.0685	0.1264	0.0143	0.0007	0.0000	0.2075	0.5826
						0.038	*0.178*	*0.093*	*0.203*	*0.056*	*0.244*	*0.285*

Analysis using employment and unemployment data from the Ministry of Labour *Gazette*, 1923–1936, for men only. Entries are coefficient estimates from the quadratic programming model described in Appendix A, representing the probability of transitioning from the row employment-sector state to the column employment-sector state. Bootstrapped standard errors, using residual resampling, are presented in italics.

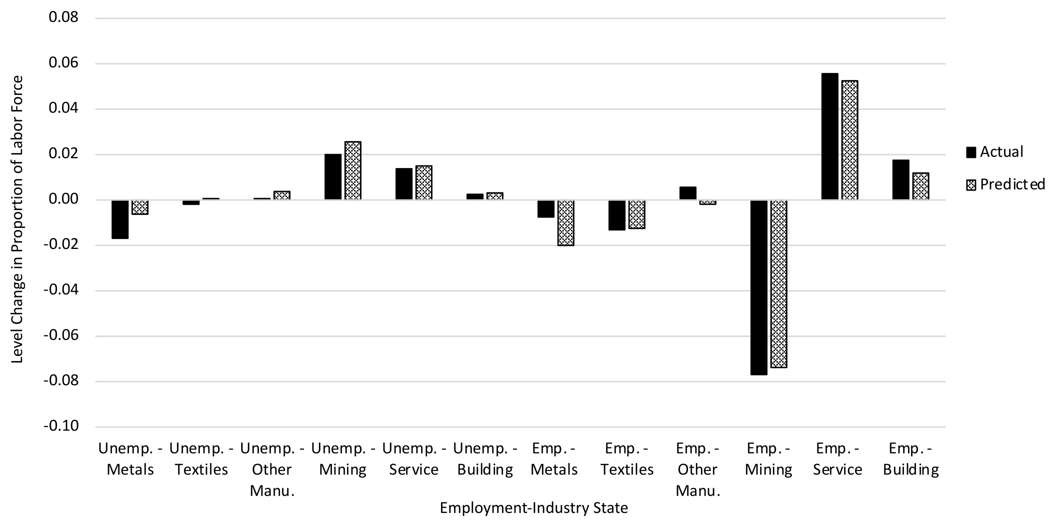
Table 8: Markov transition probabilities across employment-sector states, women only

	Unemployment						Employment					
	Metals	Textiles	Other Manu.	Mining	Service	Building	Metals	Textiles	Other Manu.	Mining	Service	Building
Unemp. - Metals	0.5856						0.0000	0.0000	0.0000	0.0000	0.4144	0.0000
	0.330						*0.110*	*0.290*	*0.237*	*0.106*	*0.264*	*0.107*
Unemp. - Textiles		0.4939					0.0000	0.1680	0.1833	0.0157	0.0335	0.1056
		0.091					*0.060*	*0.131*	*0.116*	*0.029*	*0.093*	*0.072*
Unemp. - Other Manu.			0.3301				0.0000	0.6230	0.0469	0.0000	0.0000	0.0000
			0.222				*0.106*	*0.262*	*0.198*	*0.026*	*0.223*	*0.065*
Unemp. - Mining				0.8057			0.0000	0.0000	0.0000	0.1034	0.0000	0.0909
				0.435			*0.267*	*0.373*	*0.382*	*0.231*	*0.397*	*0.100*
Unemp. - Service					0.6449		0.0362	0.0000	0.0000	0.0000	0.3188	0.0000
					0.248		*0.110*	*0.124*	*0.145*	*0.041*	*0.224*	*0.084*
Unemp. - Building						0.0000	0.0000	0.0000	0.9999	0.0000	0.0000	0.0000
						0.381	*0.275*	*0.420*	*0.340*	*0.250*	*0.434*	*0.125*
Emp. - Metals	0.0416						0.8274	0.0000	0.0000	0.0000	0.1310	0.0000
	0.046						*0.332*	*0.114*	*0.284*	*0.014*	*0.291*	*0.023*
Emp. - Textiles		0.1252					0.0001	0.8261	0.0397	0.0089	0.0000	0.0000
		0.025					*0.044*	*0.081*	*0.075*	*0.008*	*0.043*	*0.013*
Emp. - Other Manu.			0.0671				0.0001	0.0000	0.8359	0.0000	0.0969	0.0000
			0.024				*0.051*	*0.066*	*0.113*	*0.001*	*0.076*	*0.005*
Emp. - Mining				0.0000			0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
				0.355			*0.201*	*0.435*	*0.296*	*0.246*	*0.175*	*0.130*
Emp. - Service					0.0230		0.0340	0.0000	0.0625	0.0000	0.8805	0.0000
					0.017		*0.059*	*0.019*	*0.058*	*0.003*	*0.078*	*0.006*
Emp. - Building						0.0022	0.0001	0.0000	0.9976	0.0000	0.0000	0.0000
						0.301	*0.333*	*0.343*	*0.403*	*0.058*	*0.378*	*0.077*

Analysis using employment and unemployment data from the Ministry of Labour *Gazette*, 1923–1936, for women only. Entries are coefficient estimates from the quadratic programming model described in Appendix A, representing the probability of transitioning from the row employment-sector state to the column employment-sector state. Bootstrapped standard errors, using residual resampling, are presented in italics.

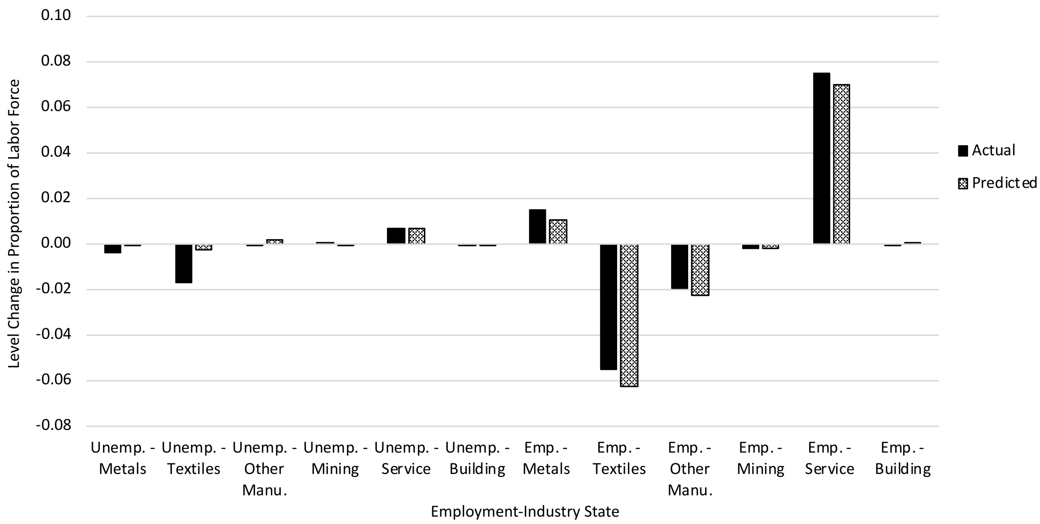
Using these estimated transition probabilities, the Markov chain can be multiplied forward 13 steps from the 1923 distribution of labor force participants across states. The predicted change in the proportion of the labor force in each state over these years, 1923 to 1936, is then the difference between the simulated 1936 proportion and the initial 1923 proportion. Figures 6 and 7 compare the predicted change in the overall proportion of the labor force in each state to the actual change for men and women, respectively. The similarities between the two series suggest that the estimated probabilities are consistent with the observed data.

Figure 6: Predicted vs. actual change in proportion of the labor force in each sector, 1923–1936, men only



Analysis using employment and unemployment data from the Ministry of Labour *Gazette*, 1923–1936, for men only. The actual figures give the level change in the proportion of the labor force in each employment-sector state in the raw data over the period. The predicted figures give the level change predicted by the Markov process estimates in Table 7 when the probabilities are projected forward by 13 steps.

Figure 7: Predicted vs. actual change in proportion of the labor force in each sector, 1923–1936, women only



Analysis using employment and unemployment data from the Ministry of Labour *Gazette*, 1923–1936, for women only. The actual figures give the level change in the proportion of the labor force in each employment-sector state in the raw data over the period. The predicted figures give the level change predicted by the Markov process estimates in Table 8 when the probabilities are projected forward by 13 steps.

The estimated transition probabilities highlight two major processes occurring in the Markov chain. First, how likely is it for an individual in a sector to become unemployed? Then, how likely are they to find a job again once they have become unemployed? Because six of the states of the Markov process correspond to unemployment and six correspond to employment, the estimated transition probabilities can be used to weight a random walk that captures some of these dynamics.

For a single person, simulating the Markov models represented by the transition probabilities in Tables 7 or 8 thirteen time steps gives a prediction for the state the individual visited on each step. For example, if we start a female worker in employment in textiles, there is an 82.6% chance they stay employed in the textile industries, a 12.5% chance they become unemployed, a 4.0% chance they move to employment in other manufacturing industries, and a 0.9% chance they move to employment in mining. Rolling a weighted die, say they move to employment in other manufacturing industries in step 1. Then, they have an 83.6% chance of staying in employment, a 6.7% chance of becoming unemployed, and a 9.7% chance of finding employment in a service industry. Rolling another weighted die, they might move to unemployment. Continuing in this fashion, the transitions for thirteen steps are simulated based on the estimated transition probabilities in Tables 7 or 8, producing a random walk. Then, the number of steps in which they ended up in any of the unemployment states can be counted.

Table 9 gives the results of simulating 120,000 men and women in the Markov chain. 10,000 individuals are started in each initial state. Using the paths that are generated, the proportion of time spent in unemployment states can be estimated. This gives an estimate of the persistence of unemployment for individuals in each initial state, taking into account the risk of becoming unemployed and the duration of that unemployment if it occurs. However, this cannot account for any variation between individuals that is not captured by their employment-sector state.

Table 9: Average percentage of time steps spent in unemployment by initial state

Initial State	Men (1)	Women (2)
Employed - Mining	16.6	13.1
Employed - Textiles	14.4	14.0
Employed - Metals	13.4	6.6
Employed - Building	13.4	8.0
Employed - Service	12.0	6.0
Employed - Other Manu.	11.1	8.5

Analysis using employment and unemployment data from the Ministry of Labour *Gazette*, 1923–1936. 120,000 individuals were simulated over 14 steps in the Markov processes represented by the transition probabilities in Table 7 in column (1) and Table 8 in column (2), with 10,000 individuals starting the process in each of the possible employment-sector states for each Markov chain. In each simulation, the proportion of time steps in which an unemployment state was visited, in any industry, was calculated. The entries in this table give the mean proportion of time steps spent in unemployment, based on the initial state in which the individual began the simulation. The results for the unemployed initial states are given in Appendix Table 15.

The results indicate that workers who began the simulation employed in the mining and textile industries experienced the most unemployment, while those who began employed in other manufacturing industries and service industries experienced the least. An employed male miner is estimated to have spent 16.6% of time steps in unemployment, while an employed male in an other manufacturing industry is only estimated to have spent 11.1% of steps in unemployment. For the thirteen years 1924–1936, this means that a man employed in mining in 1923 is estimated to have spent more than two of those years unemployed on average, whereas a man employed in an other manufacturing industry would have spent just under one and a half years unemployed on average.

The differences are even starker for women. Women in the textile industries spent the most amount of time in unemployment (14.0%), while women employed in the service industries spent the least (6.0%). This means that over the same thirteen years, a woman employed in textiles in 1923 is estimated to have spent almost two years unemployed on average, whereas a woman employed in service industries in 1923 is estimated to have spent only three quarters of a year unemployed on average.

Taken together, these results suggest that long-term unemployment was closely associated with the impediments to worker reallocation identified in the job finding rate analysis. There was significant heterogeneity by sector and gender in the likelihood of becoming unemployed and then in finding employment in another industry. The results of the simulation indicate that the most persistent unemployment was experienced by men associated with the mining industries and by women associated with the textile industries, while men and women in service industries and in other manufacturing industries experienced the least. This broadly accords with the results from Section 4, suggesting that impediments to worker reallocation were associated with more persistent unemployment throughout the interwar period.

6 Conclusion

This paper has presented new evidence on the characteristics and causes of interwar British unemployment, evaluating the role of the reallocation of jobs and workers across industries and sectors. The interwar economy was characterized by allocative shocks that generated job creation in some industries and job destruction in others. This paper finds that impediments to worker reallocation in the face of these shocks contributed to high and persistent unemployment.

The extent of worker reallocation across industries was estimated, and variations in job finding rates over time, across sectors, by gender, and by region were considered. The results indicate that interwar industries not only had large differences in their unemployment rates, but that the ability of laid-off workers to change industries depended on the industry in which they had been previously employed. Cross-industry job finding rates were particularly high for workers from service industries and building industries, whereas workers from textile manufacturing and mining industries had the fewest alternative labor market opportunities. Men faced fewer impediments to reallocation across industries than women, though this varied by industry, and the labor market was more flexible in the South East and London regions than in the North of England and in Wales. Job finding rates were higher for workers from industries that were expanding than for those from industries that were contracting, suggesting that workers in declining industries faced additional impediments to moving into other industries. The Great Depression widened this gap by increasing labor market flexibility for workers from expanding industries and decreasing flexibility for workers from contracting industries. These impediments to worker reallocation, which were experienced more acutely by some workers than others, were found to be associated with persistent unemployment in a Markov simulation.

Previously, some scholars have argued that the interwar labor market was sclerotic in aggregate, which either drove unemployment from the supply side or played a role in amplifying a demand-side shock. This paper has offered an alternative perspective, emphasizing job and worker reallocation across industries in the face of dispersed allocative shocks. Impediments to worker reallocation differed for men and women, for workers from different industries, and for workers located in different geographic regions. Some of these unequal impacts appear to have been amplified by the global Great Depression.

The evidence in this paper supports a view on the interwar British unemployment crisis that centers the role of structural change. While some historians have long noted the importance of structural change in interwar unemployment, this paper provides new econometric evidence that job and worker reallocation amidst the cyclical downturn caused some workers to experience persistent disadvantage. Today, policymakers are increasingly concerned with the disparate impacts of recessions and their policy responses on workers from different demographic and industrial groups in the economy. In the interwar British context, this paper suggests that job and worker reallocation played a role in both the scale and distribution of unemployment during the Great Depression, generating related disparities in economic outcomes almost a hundred years ago.

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Appendices

Table 10: Industries, groups, and sectors in the Ministry of Labour *Gazette*

Industry Group	Industries
Metal Manufacturing, Metal Trades, and Engineering	
Engineering, etc.	Constructional Engineering
Engineering, etc.	Electrical Engineering
Engineering, etc.	General Engineering; Engineers' Iron and Steel Founding
Engineering, etc.	Marine Engineering, etc.
Metal Manufacture	Iron and Steel Tube Making
Metal Manufacture	Manufacture of Brass, Cotton, Zinc, Tin, Lead, etc.
Metal Manufacture	Manufacture of Tin Plates
Metal Manufacture	Pig Iron Manufacture (Blast Furnaces)
Metal Manufacture	Steel Melting and Iron Puddling Furnaces, Rolling Mills and Forges
Metal Manufacture	Wire, Wire Netting, Wire Rope Manufacture
Metal Trades	Bolts, Nuts, Screws, Rivets, Nails, Etc., Manufacture
Metal Trades	Brass and Allied Metal Wares Manufacture
Metal Trades	Electrical Cable, Wire, and Electric Lamp Manufacture
Metal Trades	Electrical Wiring and Contracting
Metal Trades	Hand Tool, Cutlery, Saw, File Making
Metal Trades	Heating and Ventilating Apparatus
Metal Trades	Metal Industries Not Separately Specified
Metal Trades	Stove, Grate, Pipe, etc., and General Iron Founding
Metal Trades	Watches, Clocks, Plate, Jewellery, etc., Manufacture
Textile Manufacturing	
Textile Trades	Carpet Manufacture
Textile Trades	Cotton Industry
Textile Trades	Hemp Spinning and Weaving, Rope, Cord, Twine, etc., Making
Textile Trades	Hosiery
Textile Trades	Jute
Textile Trades	Lace
Textile Trades	Linen
Textile Trades	Silk Industry
Textile Trades	Textile Bleaching, Printing, Dyeing, etc.
Textile Trades	Textile Industries Not Separately Specified
Textile Trades	Woolen and Worsted
Other Manufacturing and Production Industries	
Brick, Tile, etc., Making	Brick, Tile, etc., Making
Chemicals, etc.	Chemicals Manufacture
Chemicals, etc.	Explosives Manufacture
Chemicals, etc.	Oil, Grease, Glue, Soap, Ink, Match, etc., Manufacture
Chemicals, etc.	Paint, Varnish, Japan, Red and White Lead Manufacture
Clothing Trades	Blouses, Shirts, Collars, Underclothing, etc., Making
Clothing Trades	Boot, Shoe, Slipper and Clog Trades
Clothing Trades	Dress Industries Not Separately Specified
Clothing Trades	Dress and Mantle Making and Millinery
Clothing Trades	Hat and Cap (Including Straw Plait) Manufacture
Clothing Trades	Tailoring
Construction and Repair of Vehicles	Construction and Repair of Carriages, Carts, etc.
Construction and Repair of Vehicles	Construction and Repair of Motor Vehicles, Cycles and Aircraft
Construction and Repair of Vehicles	Railway Carriage, Wagon, and Tram-Car Building
Fishing	Fishing
Food, Drink, and Tobacco	Bread, Biscuit, Cake, etc., Making
Food, Drink, and Tobacco	Cocoa, Chocolate and Sugar Confectionery
Food, Drink, and Tobacco	Drink Industries
Food, Drink, and Tobacco	Food Industries Not Separately Specified
Food, Drink, and Tobacco	Grain Milling
Food, Drink, and Tobacco	Tobacco, Cigar, Cigarette and Snuff Manufacture
Gas, Water and Electricity Supply Indus	Gas, Water and Electricity Supply Indus
Glass Trades	Glass (excluding Bottles and Scientific Glass) Manufacture
Glass Trades	Glass Bottle Making
Leather and Leather Goods	Saddlery, Harness and Other Leather Goods Manufacture
Leather and Leather Goods	Tanning, Currying and Dressing
Other Manufacturing Industries	Brush and Broom Making
Other Manufacturing Industries	Musical Instrument Making

Other Manufacturing Industries	Oilcloth, Linoleum, etc., Manufacture
Other Manufacturing Industries	Rubber Manufacture
Other Manufacturing Industries	Scientific and Photographic Instrument and Apparatus Manufacture
Other Manufacturing Industries	Toys, Games and Sports Requisites Manufacture
Pottery, Earthenware, etc.	Pottery, Earthenware, etc.
Printing and Paper Trades	Cardboard Boxes, Paper Bags, and Stationery
Printing and Paper Trades	Paper and Paper Board Making
Printing and Paper Trades	Printing, Publishing, and Bookbinding
Printing and Paper Trades	Stationery and Typewriting Requisites (Not Paper)
Printing and Paper Trades	Wall Paper Making and Paper Staining
Sawmilling, Furniture and Woodwork	Furniture Making, Upholstering, etc.
Sawmilling, Furniture and Woodwork	Sawmilling and Machined Woodwork
Sawmilling, Furniture and Woodwork	Wood Box and Packing Case Making
Sawmilling, Furniture and Woodwork	Woodworking Not Separately Specified
Mining	
Mining	Clay, Sand, Gravel, and Chalk Pit Digging
Mining	Coal Mining
Mining	Iron Ore and Ironstone Mining and Quarrying
Mining	Lead, Tin, and Copper Mining
Mining	Mining and Quarrying Not Separately Specified
Mining	Slate Quarrying and Mining
Mining	Stone Quarrying and Mining
Non-Metalliferous Mining Products	Artificial Stone and Concrete Manufacture
Non-Metalliferous Mining Products	Cement, Limekilns and Whiting Works
Non-Metalliferous Mining Products	Coke Ovens and By-Product Works
Services	
Commerce, Banking, Insurance and Finance	Commerce, Banking, Insurance and Finance
Distributive Trades	Distributive Trades
Miscellaneous Trades and Services	Entertainment and Sports
Miscellaneous Trades and Services	Hotel, Boarding House, Club Services
Miscellaneous Trades and Services	Industries and Services Not Separately Specified
Miscellaneous Trades and Services	Laundries, Dyeing and Dry Cleaning
Miscellaneous Trades and Services	Local Government
Miscellaneous Trades and Services	National Government
Miscellaneous Trades and Services	Professional Services
Transport and Communication	Canal, River, Dock and Harbour Service
Transport and Communication	Railway Service
Transport and Communication	Road Transport Not Separately Specified
Transport and Communication	Shipping Service
Transport and Communication	Tramway and Omnibus Service
Transport and Communication	Transport, Communication, and Storage Not Separately Specified
Building and Shipbuilding	
Building and Construction of Works	Building
Building and Construction of Works	Public Works Contracting, etc.
Shipbuilding and Ship Repairing	Shipbuilding and Ship Repairing

Sectors given in bold sub-headings. Industry groupings taken from the Ministry of Labour *Gazette*.

Table 11: Proportions insured, employed, and unemployed by gender in each industry category

	Total			Men			Women		
	Insured	Emp.	Unemp.	Insured	Emp.	Unemp.	Insured	Emp.	Unemp.
Metal Manu.	0.132	0.129	0.152	0.153	0.149	0.173	0.077	0.077	0.071
Textile Manu.	0.104	0.097	0.144	0.056	0.053	0.068	0.234	0.208	0.452
Other Manu.	0.234	0.246	0.167	0.208	0.220	0.143	0.305	0.310	0.264
Mining	0.101	0.092	0.154	0.138	0.127	0.191	0.003	0.003	0.004
Service	0.327	0.342	0.239	0.308	0.320	0.247	0.377	0.397	0.207
Building	0.102	0.094	0.143	0.138	0.130	0.178	0.004	0.004	0.002
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Entries are the total proportion of each group in each of the six industry categories over the period 1923–1936. “Insured” are proportions of those covered by the unemployment insurance scheme, both employed and unemployed. “Emp.” covers those in employment and “Unemp.” covers those out of employment. Data from the Ministry of Labour *Gazette*.

Table 12: Cross-industry job finding rate robustness to grouping of industries as expanding or contracting based on overall employment change

	Men Only		Women Only	
	Contracting (1)	Expanding (2)	Contracting (3)	Expanding (4)
1925-1929 × Δ Employed	0.18***	0.50***	-0.22***	0.46***
	(0.02)	(0.03)	(0.02)	(0.03)
1930-1933 × Δ Employed	0.02***	0.73***	-0.25***	0.51***
	(0.02)	(0.05)	(0.01)	(0.07)
1934-1936 × Δ Employed	1.08	0.57***	0.18***	0.77**
	(0.26)	(0.04)	(0.06)	(0.08)
Constant	-331.07	1711.94*	-195.54	1200.27***
	(547.29)	(693.50)	(190.35)	(348.74)
Year Fixed Effects	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes
Num. of observations	483	717	483	717
R2	0.884	0.383	0.963	0.405

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The entries are the coefficient estimates are for the model described by Equation (3) plus one, where the dependent variable is the change in unemployment from $t-1$ to t in industry i and where "Δ Employed" is the change in employment from $t-1$ to t in industry i. The estimates represent whether a decrease (increase) in employment in an industry coincided with a proportionate increase (decrease) in unemployment in the industry. Estimates near 0 indicate little to no adjustment across industries, as the entire change in employment is reflected in the change in unemployment in that industry. Estimates near 1 indicate almost perfect adjustment across industries. Contracting industries are those that had a decrease of employment overall, from $t-1$ to t, while expanding industries had an increase. Standard errors given in parentheses. Analysis using gender-disaggregated employment and unemployment data from the Ministry of Labour *Gazette*, 1924–1936.

Table 13: Cross-industry job finding rates for expanding or contracting industries, by industry category

	Metals		Textiles		Other Manu.		Mining		Service		Building	
	Contr. (1)	Expan. (2)	Contr. (3)	Expan. (4)	Contr. (5)	Expan. (6)	Contr. (7)	Expan. (8)	Contr. (9)	Expan. (10)	Contr. (11)	Expan. (12)
1925-1929 × Δ Employed	0.05***	0.00***	-0.28***	0.04***	0.36***	0.25***	0.36***	0.95	0.24***	0.95	-2.88	0.23
	(0.06)	(0.08)	(0.04)	(0.07)	(0.06)	(0.05)	(0.07)	(0.05)	(0.14)	(0.05)	(1.54)	(0.36)
1930-1933 × Δ Employed	0.02***	-0.03***	-0.20***	-0.35***	0.30***	0.41***	0.20***	1.47***	0.14**	1.47***	0.23*	0.24***
	(0.06)	(0.25)	(0.02)	(0.17)	(0.11)	(0.07)	(0.08)	(0.11)	(0.27)	(0.11)	(0.13)	(0.14)
1934-1936 × Δ Employed	0.20	0.51***	-0.06***	-0.38***	0.62*	0.53***	10.95***	0.52***		0.52***		0.56*
	(3.35)	(0.08)	(0.13)	(0.35)	(0.16)	(0.04)	(1.91)	(0.12)		(0.12)		(0.16)
Constant	-1670.11	2967.25	-3855.62**	8533.87**	5.27	2014.54***	4824.15	1346.51	-1249.27	1346.51	-73428.48	12752.26
	(1178.14)	(1533.86)	(1135.81)	(3072.47)	(525.35)	(358.64)	(2415.52)	(2365.85)	(1825.98)	(2365.85)	(38442.90)	(11541.58)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Num. of observations	97	131	62	70	210	294	56	136	44	136	14	22
R2	0.896	0.710	0.989	0.869	0.598	0.665	0.977	0.572	0.743	0.572	0.974	0.936

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The entries are the coefficient estimates for the model described by Equation (3) plus one, where the dependent variable is the change in unemployment from $t-1$ to t in industry i and where "Δ Employed" is the change in employment from $t-1$ to t in industry i. The estimates represent whether a decrease (increase) of employment in an industry coincided with a proportionate increase (decrease) of unemployment in the industry. Estimates near 0 indicate little to no adjustment across industries, as the entire change in employment is reflected in the change in unemployment in that industry. Estimates near 1 indicate almost perfect adjustment across industries. Contracting industries are those that had a decrease of employment from $t-1$ to t, while expanding industries had an increase. Standard errors given in parentheses. Analysis using employment and unemployment data for both men and women from the Ministry of Labour *Gazette*, 1924–1936.

Table 14: Robustness of estimated average cross-industry job finding rates by region to 1921 industrial composition

	Overall	By Time Period		
	1925-1936	1925-1929	1930-1933	1934-1936
South East	0.68	0.70	0.89	0.57
Greater London	0.68	0.71	0.82	0.58
East	0.65	0.65	0.81	0.58
South West	0.65	0.66	0.83	0.56
Wales 2	0.58	0.60	0.74	0.46
North 2	0.57	0.59	0.67	0.55
Midland 1	0.51	0.53	0.53	0.51
Midland 2	0.43	0.43	0.43	0.43
North 4	0.43	0.44	0.49	0.54
Wales 1	0.43	0.44	0.43	0.21
North 1	0.42	0.43	0.45	0.27
North 3	0.36	0.36	0.39	0.31

The entries are the average cross-industry job finding rates of industry-level coefficient estimates from the model described by Equation (4) plus one. For each region, the job finding rate of every industry is averaged, weighted by the proportion of the labor force, employed and unemployed, in that industry in 1921 according to the 1931 *Census of England and Wales* Industry Report Table C. The estimates represent whether a decrease (increase) of employment in an industry coincided with a proportionate increase (decrease) of unemployment in the industry. Estimates near 0 indicate little to no adjustment across industries, as the entire change in employment is reflected in the change in unemployment in that industry. Estimates near 1 indicate almost perfect adjustment across industries.

Table 15: Average percentage of time steps spent in unemployment by unemployment initial states

Initial State	Men (1)	Women (2)
Unemployed - Mining	0.416	0.587
Unemployed - Service	0.359	0.249
Unemployed - Building	0.350	0.150
Unemployed - Textiles	0.321	0.227
Unemployed - Other Manu.	0.317	0.228
Unemployed - Metals	0.266	0.221

Analysis using employment and unemployment data from the Ministry of Labour *Gazette*, 1923–1936. 120,000 individuals were simulated over 14 steps in the Markov processes represented by the transition probabilities in Table 7 in column (1) and Table 8 in column (2), with 10,000 individuals starting the process in each of the possible employment-industry states for each Markov chain. In each simulation, the proportion of time steps in which an unemployment state was visited, in any industry, was calculated. The entries in this table give the mean proportion of time steps spent in unemployment, based on the initial state in which the individual began the simulation. The results for the employed initial states are given in Table 9.

A Details on estimating Markov transition probabilities from aggregate data

With complete data, a transition matrix based on a Markov model can be used to describe labor market mobility across industries. The Markov model has a discrete number of states, S, which in this case are employment status and industry pairs. At any point in time, all labor market participants can be classified into one of these employment-industry states, representing their employment or unemployment in a specific industry. The transition matrix P describes the probability of remaining in the current state or transitioning to a different state in one time step. Each element of P, p_{ij}, gives the probability of being in state i at time $t-1$ and then moving to state j for t. P is thus:

$$P[i,j] = \begin{bmatrix} p_{11} & p_{12} & \cdots. & p_{1S} \\ p_{21} & p_{22} & \cdots & p_{2S} \\ \vdots & \vdots & \ddots & \vdots \\ p_{S1} & p_{S2} & \cdots & p_{SS} \end{bmatrix}$$

There are two relevant assumptions. First, the Markov process is assumed to be first-order stationary, so the individual probabilities p_{ij} do not change over time. Second, it is assumed that an individual's state at time t is exclusively affected by their state at time $t-1$. If x_t represents the state of an individual at time t, then this means $p_{ij} = Pr(x_t = j|x_{t-1} = i) = Pr(x_t = j|x_{t-1} = i, x_0, \ldots, x_{t-2})$.

When data is available on transitions between employment-industry states, the probability of an individual moving from state i to state j between time $t-1$ and t is simply the total number of people who moved from i to j divided by the total number of people who were in state i at time $t-1$. Letting m_{ij} represent the number of people who moved from state i to j, then:

$$p_{ij} = \frac{m_{ij}}{\sum_{j=1}^{S} m_{ij}}$$

Then, the probability of being in state j at time t is given by the relationship $q_j(t) = \sum_{i=1}^{s} q_i(t-1)p_{ij}$. This weights the probability of moving from any state i into state j from $t-1$ to t by the probability of being in state i in $t-1$. Summing over all possible states, including j, gives the overall likelihood of being in state j at time t.

In our case, we do not have data on individual industry or employment status transitions. Instead, we are restricted to aggregate data on the proportion of workers in each industry and employment status pair. Using the same framework as in the full information case, we can replace the probabilities q_j with our aggregate proportions data to estimate p_{ij} for all j and i with some error.

The aggregate data is the number of labor force participants in each employment-industry state $s \in 1, \cdots, S$ at each time $t \in [1, T]$. For each state s, we have a column vector y_s whose components $y_s(2), y_s(3), \cdots, y_s(T)$ give the proportion of individuals in the state at time t. Then,

$$y_s(t) = \sum_{i=1}^{S} y_i(t-1)p_{is} + u_s(t) \tag{5}$$

For each s, we want to estimate the column vector p_s with components representing the probability of transitioning into j from all states: $p_{1,s}, p_{2,s}, ..., p_{S,s}$. The data on the proportion of individuals in every state in every potential previous period can be written as:

$$X_s = \begin{bmatrix} y_1(1) & y_2(1) & \cdots . & p_S(1) \\ y_1(2) & y_2(2) & \cdots & y_S(2) \\ \vdots & \vdots & \ddots & \vdots \\ y_1(T-1) & y_2(T-1) & \cdots & y_S(T-1) \end{bmatrix}$$

For each state, the proportion of individuals at time t depends on the proportion of individuals in all other states, and the same state, at time $t-1$. Thus, X_s is the same for all states s, but the subscript is maintained for clarity.

Then (5) can be written in matrix form,

$$\mathrm{y}_s = X_s \mathrm{p}_s + \mathrm{u}_s$$

and put into a system of equations for all s. However, the equations for one of the states s are redundant because y is a series of proportions, p are probabilities that sum to 1 across states, and X is also given in proportions. Removing the final state S gives the system:

$$\mathrm{y} = X\mathrm{p} + \mathrm{u},$$

where

- y is the vector $[\mathrm{y}_1^\top, \mathrm{y}_2^\top, ...\mathrm{y}_{S-1}^\top]^\top$, which has the dimensions $((T-1)(S-1)) \times 1$
- X is a block diagonal matrix of dimension $((T-1)(S-1)) \times (S(S-1))$ where $X_1 = X_2 = \cdots = X_{S-1}$:

$$X = \begin{bmatrix} X_1 & 0 & \cdots . & 0 \\ 0 & X_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & X_{S-1} \end{bmatrix}$$

- p is $[\mathrm{p}_1^\top, \mathrm{p}_2^\top, ..., \mathrm{p}_{S-1}^\top]^\top$ with the dimensions $(S(S-1)) \times 1$.

The final system thus looks like:

$$
\begin{bmatrix} y_1(2) \\ y_1(3) \\ \vdots \\ y_1(T) \\ y_2(2) \\ \vdots \\ y_2(T) \\ \vdots \\ y_{S-1}(2) \\ \vdots \\ y_{S-1}(T) \end{bmatrix} = \begin{bmatrix} X_1 & 0 & \cdots . & 0 \\ 0 & X_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & X_{S-1} \end{bmatrix} \begin{bmatrix} p_{1,1} \\ p_{2,1} \\ \vdots \\ p_{S,1} \\ p_{1,2} \\ \vdots \\ p_{S,2} \\ \vdots \\ p_{1,S-1} \\ \vdots \\ p_{S,S-1} \end{bmatrix} + \begin{bmatrix} \mathbf{u}_1 \\ \vdots \\ \mathbf{u}_{S-1} \end{bmatrix}
$$

The transition probabilities p can be estimated using least squares with linear constraints so long as $(T-1) \geq S$. We require the transition probabilities to be between 0 and 1, inclusive, and for the rows of $P[i, j]$ to sum to 1. Following Walshe (2016) and Jones (2005), this can be written as the quadratic programming problem minimizing the sum of squared residuals subject to constraints:

$$
\begin{aligned}
\underset{\mathrm{p}}{\text{minimize}} \quad & \mathrm{u}^\top \mathrm{u} = (\mathrm{y} - X\mathrm{p})^\top (\mathrm{y} - X\mathrm{p}) \\
\text{subject to} \quad & G\mathrm{p} \leq \eta, \quad G_{S\times(S(S-1))} = [I_1, I_2, \ldots I_{S-1}] \quad \eta_{S\times 1} = [1, 1, ..., 1]', \\
& \mathrm{p} \geq 0
\end{aligned}
\tag{6}
$$

The first constraint ensures that each transition probability is less than or equal to one and that the probabilities of transitioning from a state s at a given time t sum to 1. The second constraint forces the probabilities to be greater than or equal to zero. Additional constraints can be used to assign $p_{i,j}$ for some i and j to a specific value, such as zero, as in the application.