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Transitional costs and the decline in coal: Worker-level evidence

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Abstract
The outside options available to workers critically determine the transitional costs of labor demand shocks. Using comprehensive administrative data, we examine the worker-level effects of the decline of coal — a regionally concentrated labor demand shock that reduced employment by more than 50% between 2011 and 2021. We show that coal workers experienced very large, persistent earnings losses compared to similar workers less connected to coal. In contrast to worker-level analyses of labor demand shocks in more spatially diffuse industries, we show that non-employment is an important margin through which adjustment operates. Workers also earn substantially lower earnings when employed. Moving between industries or regions does little to mitigate losses. Instead, we observe significant increases in SSDI receipt. Our findings suggest that transitional costs are higher in regionally concentrated industries when skills do not easily transfer across sectors.

Keywords: decline of coal, earnings, workers, non-employment, technological change
JEL codes: J0; J6; Q4

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1 Introduction

Coal fueled the industrial revolution and laid the foundation for modern growth during the 19th and 20th Centuries. Without coal, the rapid technological change and economic progress that transformed the modern world would have been inconceivable. Yet, in the span of a decade, coal has collapsed. In the last decade, coal production and employment in the United States has declined by more than 50% (U.S. Energy Information Administration, 2023). This abrupt decline, largely driven by technological advances such as the shale gas revolution and substantial cost reductions in wind and solar generation (Kolstad, 2017; Linn and McCormack, 2019; Coglianese et al., 2020; Davis et al., 2022), has fundamentally changed energy production in the U.S., and in doing so reshaped the lives of coal workers and their communities.

We examine the worker-level consequences of the coal industry's precipitous decline using comprehensive employer-employee data from the U.S. Census Bureau and Internal Revenue Service (IRS). Our data includes the universe of individuals employed in coal mining establishments between 2005 and 2021. Emerging evidence suggests that communities categorized as being dependent on coal have experienced reductions in employment, earnings, and local tax revenues (Morris et al., 2019; Hanson, 2022; Blonz et al., 2023; Krause, 2023). Aggregate statistics, however, mask many possible margins of adjustment and tell us little about how coal workers have been affected by the decline of coal. Affected workers may have adapted quickly moving to new industries or labor markets. Alternatively, workers may have faced substantial transitional costs due to lost skills and moving costs. Understanding how workers have adjusted to this reduction in labor demand is crucial for assessing the transitional costs of coal's decline, and for informing efforts to minimize the distributional labor market consequences of the broader shift away from fossil fuels. A particular feature of the decline of coal is its regional concentration, potentially yielding insights distinct from analyses of labor demand shocks in spatially diffuse industries like manufacturing, where workers may have had greater outside options, mitigating transitional costs (Jacobson et al., 1993; Walker, 2011; Autor et al., 2014).

We begin by characterizing the coal mining workforce, detailing workers' demographic profiles, earnings distributions, and geographic locations. Coal workers are predominantly male and non-Hispanic white, with significantly lower college attainment rates compared to the broader workforce. Despite this educational gap, coal workers command substantially higher average earnings. The location of coal workers is highly concentrated in Central Appalachia and parts of the Mountain West due to the spatial concentration of coal deposits. This contrasts with other sectors and industries, where workers are distributed more evenly across space. The spatial concentration of coal may increase competition for local jobs, the supply of which could be affected if displacements from the coal industry reduce demand for local goods and services. If there are limited local opportunities, coal workers may have to search beyond their own labor market to find comparable work. We document that 80 percent of workers separated from coal during our sample period and that non-employment is the modal activity for the plurality (33 percent) of workers in the years outside of coal.

To better understand the consequences for workers, we first descriptively evaluate the consequences of worker separations. We estimate that coal worker separations are associated with large and persistent reductions in earnings. By contrast, we estimate that non-coal worker separations, on average, are associated with a temporary reduction in earnings followed by a return to trend in earnings within a couple of years. This analysis is limited in two important ways. First, the decision to separate from a firm may be voluntary, which can be beneficial to workers (Topel and Ward, 1992; Hahn et al., 2021). Second, while we could improve identification by exploiting firm closures or "mass layoff" events, which have been shown to result in persistent earnings losses (Jacobson et al., 1993; Couch and Placzek, 2010), a focus on separations misses many broader margins of adjustment through which industry decline can affect workers.

To mitigate identification concerns and provide a broader understanding of the decline of coal on workers we exploit differential worker-level exposure to the post-2011 "coal shock" — the period in which U.S. coal mining employment declined by more than 50 percent, largely due to plausibly exogenous macroeconomic factors, notably the influx of cheaper natural gas due to advances in hydraulic fracturing technologies (Kolstad, 2017; Linn and McCormack, 2019; Coglianese et al., 2020; Davis et al., 2022).[1] We measure workers' exposure based on their pre-shock "attachment" to the coal mining industry, defined by their employment history in the years preceding the decline of coal. The richness of our data allows us to estimate differences in outcomes between workers that are observationally similar across a broad range of individual-level characteristics.

Between 2012 and 2019, workers employed full-time in coal mining pre-shock experienced cumulative earnings declines equivalent to 1.6 times their 2007–2011 average annual earnings. This reduction in earnings is driven by a combination of working fewer years (one-third of a year less than less exposed workers) and reductions in earnings conditional on being employed (17 percent less). Our finding that the reduction in cumulative earnings is driven by both additional years with zero earnings and reductions in within-year earnings is distinct from previous worker-level studies examining the consequences of trade shocks and environmental regulations (Walker, 2013; Autor et al., 2014). The transitional costs associated with the decline of coal appear to be more substantial than in other contexts.

We decompose coal worker responses into four distinct components: effects associated with the initial employer; effects associated with separation; effects associated with relocation between employers, industries, and or labor markets; and effects associated with government transfers. By decomposing our main estimates along these margins we identify where in the adjustment process frictions may impede workers, and which types of workers are most affected.

Looking across sectors, we show that losses are driven by years in which workers are not in working coal. Within the coal industry workers experience meaningful reductions in earnings per year of employment (12-16 percent lower annual earnings), but don't spend fewer years of employment within industry compared to control workers. If anything, more exposed workers remain in industry longer than control workers. The re-

[1] Coglianese et al. (2020) attribute 92 percent of the decline in coal production between 2008 and 2016 to the falling price of natural gas relative to coal, with environmental regulations accounting for an additional six percent.

duction in earnings outside of coal is driven by a substantial increase in non-employment, as well as much larger reductions in earnings per year of employment (30 percent lower annual earnings) compared to control workers.

Looking across labor markets, we find no strong evidence that geographic mobility is an important margin through which adjustment operates. Losses are driven by years in which workers are outside of their industry but remain within their initial commuting zone; however, workers experience similar reductions in earnings per year of employment whether they remain in their initial labor market or a different labor market. On average, more exposed workers are no less likely to remain in the initial labor market than control workers. Taken together, we find little evidence that relocating across labor markets or industries recoups lost earnings.

Exploring the role of government transfers, we estimate that more exposed workers receive significant increases in Social Security Disability Insurance (SSDI) payments compared to control workers. These findings suggest that coal workers may recoup some losses, but through what is arguably a "second-best" transfer mechanism.

Our findings contribute to the literature on the decline of coal by examining worker-lever effects, building on an extensive body of work on community-level analysis (Black et al., 2002, 2003, 2005; Jacobsen and Parker, 2016; Morris et al., 2019; Hanson, 2022; Krause, 2023). These existing studies provide compelling evidence that the decline of coal has adversely affected connected communities, with consequences ranging from large declines in total employment and average wages to increased reliance on government transfers. However, the underlying mechanisms – whether these results reflect shifts in population composition or individual losses – remain ambiguous.[2] We provide comprehensive evidence on individual workers' margins of adjustment following the post-2011 contraction in coal demand. Our detailed residential and employment histories allow us to decompose aggregate effects along various margins of adjustment, revealing that relocation across industries and geographic mobility are not important margins through which the

[2]Rud et al. (2024) examine the worker-level earnings effects associated with separation from the coal industry in the UK context, using a "mass layoff" approach.

transitional costs are mitigated. Instead, increased receipt of government transfers appears to be an important margin of adjustment.

We also contribute to a broader literature on the transitional costs of labor demand shocks. Previous studies have shown that job displacement can lead to substantial and persistent earnings losses, particularly in distressed labor markets or during economic downturns (Topel, 1990; Blanchard and Katz, 1992; Jacobson et al., 1993; Davis and von Wachter, 2011; Walker, 2013; Autor et al., 2014; Notowidigdo, 2020; Lachowska et al., 2020; Schmieder et al., 2023). While existing work has focused on the consequences of "trade shocks" (Autor et al., 2014; Pierce and Schott, 2016; Acemoglu et al., 2016; Hakkala and Huttunen, 2016; Keller and Utar, 2023) or environmental regulations (Greenstone, 2002; Walker, 2011, 2013), our study examines a more regionally concentrated shock. While coal mining represents a small share of total employment, it accounts for a meaningful share of local employment in coal-rich regions. The regional concentration of coal mining may exacerbate the consequences of these reductions in labor demand due to increased competition over a smaller set of outside options. Moreover, the highly specialized skills developed in coal mining may not be valued as highly in other industries Neal (1995). Consistent with this, our findings demonstrate that neither reallocation across industries nor labor markets appear to significantly mitigate transitional costs. In contrast with the existing literature, we find that non-employment is a key margin through which adjustment operates in this context.

The remainder of this paper is organized as follows. We describe the construction of our data in section 2. In section 3, we present new facts about the demographic characteristics, earnings, and geographic distribution of coal workers, and describe the ways in which these characteristics have evolved over time. We also present facts about job separations in coal mining and describe how earnings and income evolve with these separations. In section 4, we detail our quasi-experimental approach and present estimates of the worker-level response to the coal shock. Section 5 concludes.

2 Data and Sample Construction

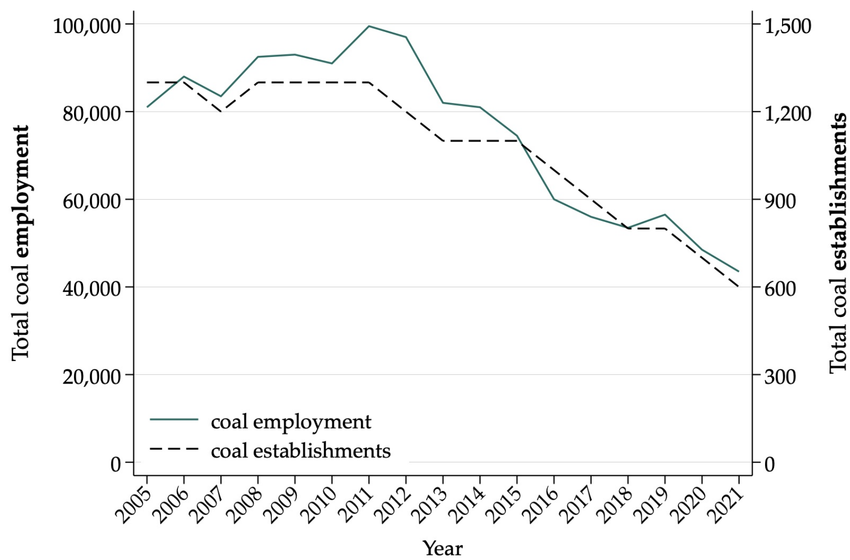
Building on the data linkages developed in Colmer et al. (2022), we combine the Census Environmental Impacts Frame (Voorheis et al., 2023) with administrative tax records (Forms W-2 and 1040) and the American Community Survey (ACS) to construct a balanced panel of the 2005–2021 employment, wage, and location histories of all individuals whose primary source of earnings in any year during the 17-year period of study was at an establishment in the coal mining industry.

We identify coal mining establishments in the Census Bureau's County Business Patterns Business Register (CBP-BR) and Longitudinal Business Database (LBD) as those with NAICS codes 2121 (coal mining) or 213113 (support activities for coal mining). We identify all employers (indexed by IRS Employer Identification Numbers, EIN) associated with these coal mining establishments using EIN-establishment links in the Business Register. Between 2005 and 2021, there were at most about 1,300 distinct coal mining establishments in a given year, but the number of coal mining establishments has declined precipitously since 2011 (Figure 1).

To construct a comprehensive panel of U.S. coal workers, we begin with the Environmental Impacts Frame (EIF) (Voorheis et al., 2023). The EIF is a microdata infrastructure that constructs consistent residential histories, and provides basic demographic information (age, race, ethnicity, and sex) for nearly the entire U.S. population using several sources of administrative data available within the Census Bureau. We identify the set of workers ever employed in coal mining by linking the EIF to the universe of IRS Form W-2s, using the EIN for the employer from which the worker received the greatest earnings in each year. If an EIN-year pair includes multiple establishments, we link the worker to the establishment that is geographically closest to the worker.[3] Our sample comprises individuals who receive W-2 earnings from a coal mining establishment in at least one year between 2005 and 2021. We construct a balanced panel dataset for these individuals, combining the EIF and W-2s to capture worker demographics along with complete

[3]We define geographic proximity based on the straight-line distance between the latitude and longitude of the worker in the EIF and the establishment in the CBP-BR. Our results are insensitive to matching workers to industries based on the (employment-weighted) modal industry within an EIN-year.

Figure 1: Total coal mining establishments & employment, 2005–2021



Note: This figure shows the total number of coal mining establishments (on the left axis) and total coal mining employment (on the right axis) between 2005 and 2021. Workers are identified as coal miners if their primary employer (in terms of total earnings) in a given year was a coal mining establishment. Coal mining establishments are defined as those with NAICS codes 2121 and 213113. The number of employees and establishments are both rounded in line with Census disclosure rules. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s, and Census Business Register.

employment and residential histories over this period, including years in which workers do not work in coal, or do not work at all. We augment this employer-employee panel with firm characteristics from the LBD, including total employment, revenue, and industry information. To further enrich our dataset, we incorporate additional demographic information for the approximately 20 percent of the sample who responded to the American Community Survey (ACS). This includes education, occupation, marital status, and family structure.[4]

Our comprehensive coal worker panel consists of approximately 218,000 individuals whose primary source of W-2 income was a coal mining establishment in at least one year between 2005 and 2021. Because we define a worker's place of employment by the NAICS code of his or her establishment, our definition of coal mining employment includes individuals engaged in support roles within the establishment as well as individuals directly

[4]These characteristics are measured in the year in which the worker responded to the ACS.

employed as coal miners. We also capture individuals who work only part-time or relatively few hours in the industry, as long as it is their primary source of W-2 earnings in any given year. The coal workforce peaked at over 99,000 in 2011, and then fell by over 50 percent over the subsequent decade (Figure 1).[5] This precipitous decline in coal demand, which we term the recent "coal shock", was primarily driven by macroeconomic factors, notably the advent of inexpensive natural gas due to advances in hydraulic fracturing technologies (Kolstad, 2017; Linn and McCormack, 2019; Coglianese et al., 2020; Davis et al., 2022).[6]

In addition to the panel covering the universe of coal workers, we define an age-restricted panel of around 142,000 coal workers who were born between 1955 and 1985, such that they are between the ages of 20 and 66 throughout the entire study period, and at most 64 by 2019.[7] We provide descriptive statistics covering both the comprehensive panel and age-restricted panel of coal workers, spanning 2005–2021.

For our quasi-experimental analysis, we supplement the age-restricted panel of coal workers with an identically constructed panel containing the employment and residential histories of a random 10-percent subsample of workers born between 1955 and 1985 who responded to the 2010 ACS.[8] We focus our analysis on individuals in this combined coal and non-coal panel who worked "full-time" in each of the five years preceding the recent coal shock (2007 to 2011), where full-time is defined as reporting earnings in excess of what one would earn by working at least 1,600 hours (about 30 hours per week) at the federal minimum wage.[9] We omit a small number of workers who died during the sample period, those whose location could not be determined, and those with negative AGI,

[5] Our coal employment figures differ slightly from official government statistics. Appendix Figure A1 our data with County Business Pattern (CBP) estimates, which closely align with Mine Safety and Health Administration (MSHA).

[6] This period of declining demand for coal is not the first shock to affect the industry. The coal industry has historically experienced multiple boom-bust cycles. For instance, previous studies have investigated the effect of the surge in demand for coal during the 1970s and the subsequent collapse in the 1980s on Appalachian coal communities (Black et al., 2002, 2003, 2005).

[7] This restriction omits about 35 percent of the original panel of workers who ever worked for a coal mining establishment. This omitted group is composed of roughly equal numbers of young (born after 1985) and old (born before 1955) coal workers.

[8] Our conclusions are robust to different subsampling strategies.

[9] In 2011, this means that reported earnings were at least $11,600.

leaving a final sample of around 152,000 individuals.[10] Of these, about 29,500 worked full-time in the coal industry in every year between 2007 and 2011, while the remainder were employed full-time in other industries during at least some of these pre-shock years. Our quasi-experimental analysis concludes in 2019 to avoid the potentially confounding effects of the Covid-19 pandemic and its associated economic disruptions. Our findings are robust to including this period.

3 Descriptive Evidence

In this section, we provide descriptive facts that characterize coal workers and industry-level patterns. We then present descriptive estimates of the evolution of workers' earnings after separating from coal, and compare our findings with the worker-level consequences of non-coal separations.

3.1 The Coal Workforce

Table 1 presents the demographic and earnings characteristics of coal and non-coal workers. The statistics in column 1 are based on the comprehensive coal worker panel, including the entire universe of individuals who worked for a coal mining establishment as their primary source of earnings at some point during the period of analysis. The statistics in column 2 are based on the sample of 29,500 full-time coal workers born between 1955 and 1985. This group of workers — with significant tenure in the coal industry and greater exposure to the subsequent coal shock — serves as the treated group of workers in our quasi-experimental analysis. We refer them as exposed coal workers going forward. Column 3 provides summary statistics for the age-restricted group of workers who worked full-time between 2007 and 2011, but who did not work for a coal establishment in all five of these years. This group of workers — with less exposure to the recent coal shock — serves as the control group in our quasi-experimental analysis.

Comparing that statistics in columns 1 and 2, we see that exposed coal workers are

[10] Sample sizes are rounded to the nearest 100 or 1,000 in line with Census disclosure rules.

Table 1: Characteristics of workers

	(1) All coal workers	(2) FT ("treated") coal workers	(3) FT ("control") workers
Male (%)	92.73	95.92	67.84
	(25.96)	(19.79)	(46.71)
Non-Hispanic white (%)	91.29	95.12	81.63
	(28.20)	(21.55)	(38.72)
College degree (%)	9.95	6.79	37.67
	(29.93)	(25.15)	(48.46)
Homeowner (%)	84.00	90.78	81.32
	(36.66)	(28.94)	(38.97)
Age	40.6	43.0	41.6
	(14.6)	(9.0)	(8.9)
Wages ($1,000s)	63.84	92.02	76.64
	(312.9)	(47.67)	(148.2)
AGI ($1,000s)	94.61	110.9	110.4
	(1276)	(103.5)	(424.2)
Observations	218,000	29,500	123,000

Sources: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register. Age, earnings, and Adjusted Gross Income (AGI) refer to 2011 values, with earnings and AGI adjusted to 2019 dollars. Educational attainment and homeownership status are drawn from ACS. Non-coal workers were identified from the 2010 ACS, and thus educational attainment and homeownership for these observations are 2010 reported values. These characteristics for coal workers are measured in the year in which the respondent took the survey, which may differ from 2010. The number of observations used to compute the means for the variables indicated may differ from the total number of observations indicated in the final row, as only about 20 percent of coal workers are matched to the ACS, and some workers who ever worked for coal (column 1) have missing wages or AGI in 2011. The sample in column 1 is the comprehensive coal panel. The sample in column 2 is exposed coal workers working full-time in coal from 2007 to 2011, defined in the text. The sample in column 3 is other full-time workers who worked in coal for fewer than five years between 2007 and 2011, defined in the text. Standard deviations are in parentheses.

slightly more likely to be male (93% vs. 96%), white (91% vs. 95%), older (43 vs. 41), and slightly less likely to have a college degree (7% vs. 10%) than the population of coal workers as a whole. They are more likely to be homeowners (91% vs. 84%). We also observe that our sample of "more exposed" coal workers earn substantially more than the population of coal workers as a whole ($92k vs. $64k). This is likely due to differences in tenure as well as the inclusion of part-time workers in column 1. The difference in adjusted gross incomes is smaller ($110k vs. $94k).

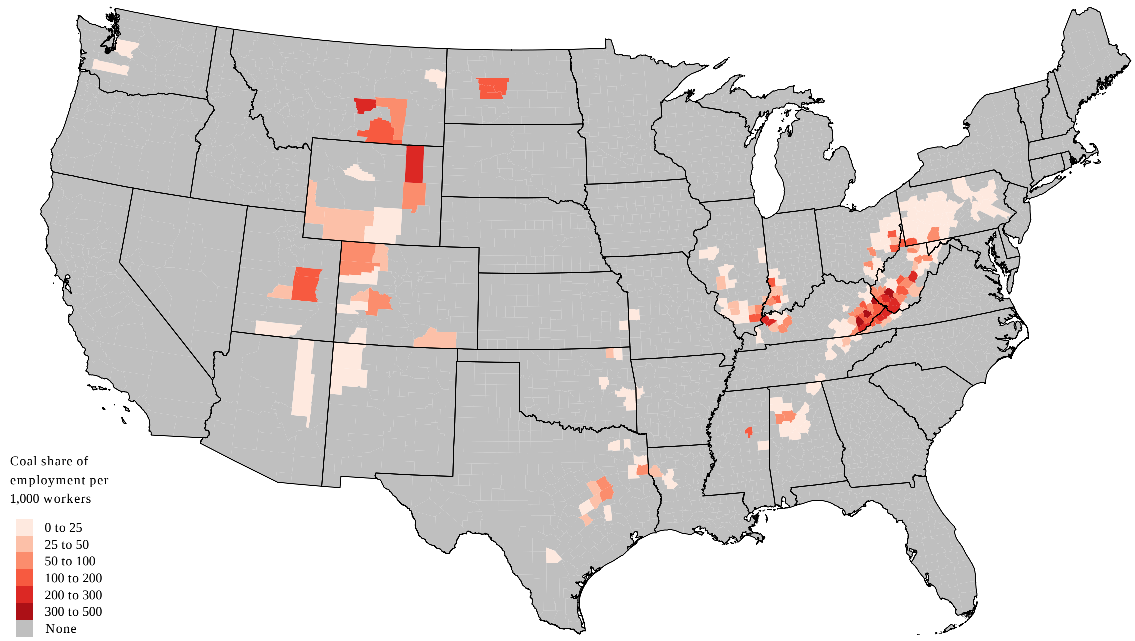
Comparing the statistics in columns 2 and 3, exposed full-time coal workers are substantually more likely to be male (95% vs. 68%), white (95% vs. 82%), and substantially less likely to have a college degree (7% vs. 38%) than full-time workers less exposed to the macroeconomic decline in coal. Despite having lower educational attainment, the average full-time coal worker received roughly $16,000 more in total wages (W-2 earnings) in 2011 than other full-time workers in the sample. That coal offers relatively high wages to individuals with relatively low levels of educational attainment foreshadows the potentially disruptive consequences that contractions in demand for coal could have for exposed workers after separating from coal. The adjusted gross incomes of the two groups of full-time workers were roughly similar in 2011.

Due to the high spatial concentration of coal deposits, the geography of coal mining employment tends to be highly concentrated, with large concentrations of workers in Central Appalachia and parts of the Mountain West. Figure 2 maps the concentration of coal mining employees as a share of total employment in 2011 across the continental United States. County-level coal mining employment is from the Mine Safety and Health Administration (MSHA), where employment is based on the county in which the coal mine is located. Total employment is retrieved from the public Quarterly Census of Employment and Wages (QCEW) data.[11] While 50 percent of counties with any coal employment hosted relatively few numbers of coal workers (median=16 coal workers per 1,000 employees), the right tail of the distribution is very long. A county at the 95th percentile of the distribution among counties with any coal mining employment had 227 coal mining workers per 1,000 employees. A county at the 99th percentile had 361 coal workers per 1,000 employees. As a point of contrast, we compare this to the construction industry. Among counties with any construction employment in 2011, the median county had 40 construction workers per 1,000 employees, a county at the 95th percentile of the distribution had 94 construction workers per 1,000 employees, and a county at the 99th percentile

[11]We use previously released aggregate statistics for these maps to avoid additional disclosure from our microdata, noting that while these aggregate statistics deviate slightly from the confidential Census data, there are no qualitative differences between aggregates from the internal microdata and the public use statistics.

of the distribution had 143 construction workers per 1,000 employees.[12]

Figure 2: Coal share of employment, 2011



Note: This figure shows the coal mining share of total employment in 2011. Coal mining employment is defined as the number of workers employed at coal mines in the county, based on data from the MSHA. Total employment is retrieved from the QCEW. Source: public data from MSHA and QCEW

Another way to evaluate the spatial concentration of industry is to calculate the industry's geographic Herfindahl–Hirschman index (HHI):

$$HHI_j = \sum_i s_{ij}^2$$

where s_{ij} is county i's share of total employment in industry j. The HHI is produced by summing the square of each share across all counties. The resulting HHI for coal mining is 164.5, which is more than four times larger than other major industries, including construction (36), manufacturing (36), and trade, transportation, and utilities (40).[13] The right tail of coal mining employment is predominately composed of counties in Eastern Kentucky and West Virginia. As a share of the U.S. coal workforce in 2011, the

[12]County-level construction employment is based on estimates produced by the QCEW.
[13]We derive county-level employment in these industries from the QCEW.

largest numbers of coal workers were located in West Virginia (hosting 26% of the coal workforce), Kentucky (20%), Pennsylvania (9%), Wyoming (7%), and Virginia (6%).[14]

Coal communities are typically situated in more rural settings where the local economy has centered around coal extraction and processing. Employment opportunities outside coal are often thought to be limited due to the lack of outside options within the community and the relative distance to more urban areas (Partridge et al., 2013; Carley et al., 2018). Given these considerations, the adjustment costs associated with local labor demand shocks may be higher in these communities than those associated with labor demand shocks experienced in more urban or economically diversified contexts.

3.2 Job separations in coal

As documented in Figure 1, the number of coal workers declined substantially between 2011 and 2021. Here, we describe separations from coal mining establishments, including the number and frequency of these separations as well as descriptive evidence on the evolution of earnings prior to and following separations from the industry.

3.2.1 Separations from coal mining establishments

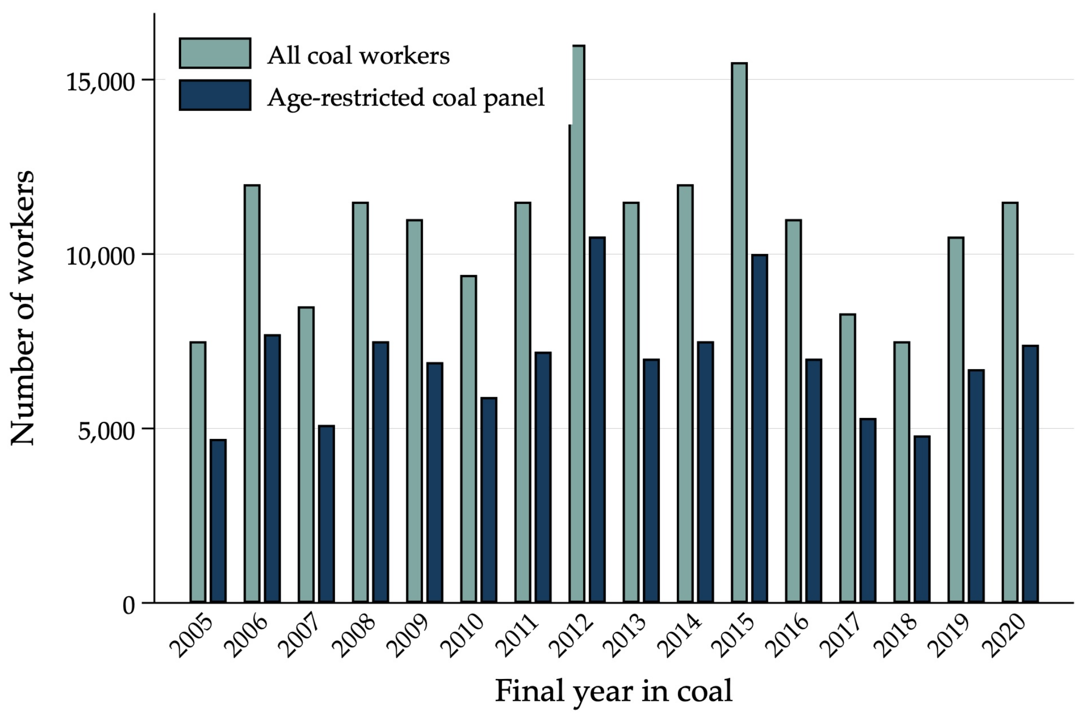
Of the 218,00 workers whose primary labor income was earned at a coal mining establishment in at least one year between 2005–2021, 174,000 (80 percent) separated from coal. We define a separation from the industry as transitioning from a state in which a coal mining establishment is a worker's primary source of earnings to one in which it is not. This separation could occur because the worker transitions to working for a non-coal establishment or because the worker transitions into a state of not earning wages (e.g., to enter unemployment or retirement).[15] Many workers transition into and out of working for a coal mining establishment over the sample period. In Figure 3 we summarize the timing

[14] Individual workers might commute across county or state lines to work in coal mines. These state-level statistics are based on mine-level data from the MSHA and thus do not capture the location of residence of the worker, but the location of employment. Our individual-level data distinguishes between location of residence and location of employment.

[15] This could also reflect a worker transitioning from a state in which coal is their primary source of earnings to their secondary source of earnings.

of final separation, defined as the last year in which the a worker's primary earnings were drawn from the coal mining industry during our study period. We omit the final year of our sample, 2021, to avoid the mechanical classification of it being a worker's final year in coal. The peak "final" year in coal mining was 2012, followed closely by 2015. The frequency of separations was evenly distributed across other years. This is consistent with the conclusions drawn from Figure 1, which showed that the decline in total coal mining employment was relatively steady after 2011.

Figure 3: Final separations from the coal industry by year, 2005–2020



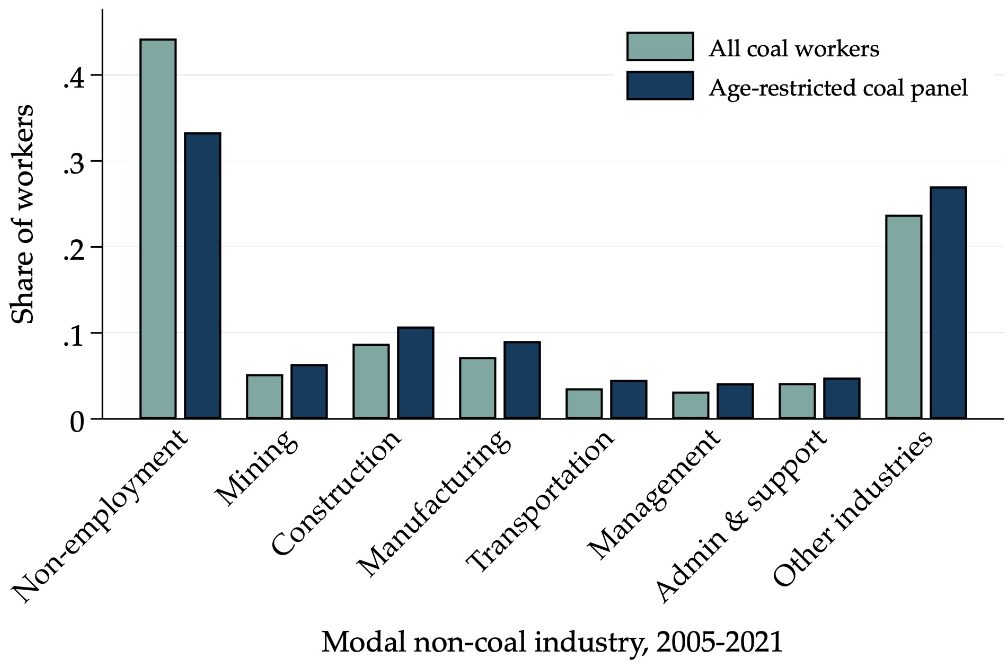
Note: Final year is defined as the final fiscal year in which the worker's primary earnings were drawn from the coal mining industry over the sample period. All coal workers includes all workers whose primary earnings were drawn from the coal mining industry in any year over the 2005–2021 period who separated from the industry over the sample period. The age-restricted coal panel further restricts this sample to individuals born between 1955 and 1985. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s, and Census Business Register.

Our data indicate that annual employment figures in the coal mining industry in any given year significantly understate the total workforce that has relied on this industry as a primary income source. The cumulative number of individuals whose main earnings derived from coal mining between 2005 and 2021 (218,000) is more than double the industry's peak employment 2011 (99,500) and over five times the current workforce. This suggests there is substantial churn in the coal workforce, with workers moving in and out of coal mining and many workers only employed in the industry for brief spells. Appendix Figure A2 plots the distribution of total years of primary employment in coal mining over the 2005–2021 period. Over half of the workers in our sample were primarily employed in coal mining for fewer than five years during this 17-year span. This pattern persists even when considering the age-restricted sample, with 47 percent of this cohort employed in coal for fewer than five years over the 15-year period from 2005–2019. This figure likely understates total industry tenure, as it does not capture workers still connected to the industry in a part-time capacity while earning more income at a non-coal employer. It also doesn't account for employment histories predating 2005. Nevertheless, our findings indicate that a large share of workers are only marginally attached to the industry, which could attenuate the consequences of coal's decline.

To describe the labor market outcomes of coal workers during non-coal employment years, we analyze their primary sources of earnings and the prevalence of non-employment. For each worker in our coal panel, we determine the modal 2-digit NAICS industry of primary earnings across non-coal years. We include non-employment, defined as reporting no W-2 earnings, as its own category. For instance, a worker with eight years in coal, five in manufacturing, and two in management would be classified as having manufacturing as their modal non-coal industry. For a worker with three years in coal, two in construction, and ten years of non-employment, the modal non-coal industry would be classified as non-employment.

Figure 4 shows that non-employment is the predominant state for 44 percent of all coal workers during their non-coal years. To mitigate the potential for confounding effects from education or retirement, we recalculate this distribution for our age-restricted sample. Even within this working-age cohort, non-employment remains the modal non-coal industry for the plurality (33 percent) of workers. Among remaining sectors, coal workers are most commonly employed in construction (10%), manufacturing (9%), and other mining (6%).

Figure 4: Modal industry during non-coal years



Note: All coal workers refers to all workers whose primary earnings were drawn from the coal mining industry in any year over the 2005–2021 period. The age-restricted coal panel further restricts this sample to individuals born between 1955 and 1985. Modal industry refers to the most frequent industry from which the worker earned his or her primary wages in the years in which coal was not the primary source of earnings. Non-employment is included as an "industry" of employment when calculating modal industry of employment. Industries are defined based on 2-digit NAICS codes: Mining (21), Construction (23), Manufacturing (31–33), Transportation and warehousing (48–49), Management of Companies and Enterprises (55), Administrative and Support and Waste Management and Remediation Services (56). Other includes all other 2-digit NAICS codes. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s, and Census Business Register.

3.2.2 The evolution of earnings following industry separations

In this section, we offer descriptive evidence on the earnings trajectories of workers following separations from the coal industry. We define a separation or "switch" event as a transition between firms from year t to $t+1$, including transitions to non-employment.[16] We focus on industry separation events in which a worker switches from working in coal

[16] We base our definition of firm on the firm ID as classified by the LBD. In most cases, this is the same as the firm's EIN code. However, if a firm has multiple employer entities (EINs), the firm ID will differ from the EIN code. Identifying a firm "switch" based on EIN code produces nearly identical results to those presented here.

in year t to not working in coal in year $t+1$.[17]

We contrast these coal separations against non-coal separations, which are defined as all firm separations that are not between the coal industry. For this analysis, we combine the age-restricted coal panel to the random sub-sample of 2010 ACS respondents and limit the sample to workers who were employed (i.e., received positive earnings) in years t and $t-1$, such that they worked at least two consecutive years prior to defining the separation event. We include all years 2005 through 2021 in the analysis, but our results are robust to omitting the pandemic years, 2020 and 2021.

We summarize the evolution of earnings prior to and following a separation event using the local projections estimator (Jordà, 2005, 2023). The local projections estimator provides a separate estimate for each horizon of interest, imposing limited structure on the underlying data generating process.[18]

For each time-horizon h, we estimate the following specification,

$$\Delta y_{i,t+h} = \beta^h Switch_{it} + X_{it}^{'} + \alpha_i + \gamma_t + \delta_r + \varepsilon_{it} \tag{1}$$

where $\Delta y_{i,t+h}$ is the difference in earnings for worker i at each time horizon $t+h$, compared to $t-1$. $Switch_{it}$ is an indicator equal to one if worker i separates firms between year t and $t+1$, and zero otherwise.[19]

In our most parsimonious specification, we include no worker-level covariates or fixed effects such that β_h reflects the unconditional variation in the data. We build on this

[17] Because we define coal workers based on their primary source of earnings, a transition from working in coal as a primary source of earnings to a secondary source of earnings will be defined as a separation event. Not included in this definition are workers who switch from a coal establishment to a non-coal establishment but remain employed at the same firm. Because we match workers to establishments based on the EIN codes of the firms from which they received their primary earnings and use geographic location to determine a worker's establishment in the relatively rare cases for which multiple establishments are associated with the same firm in a given year, there is likely greater measurement error associated with within-firm "switching." Our results are qualitatively similar to using a relatively broader definition of separations which identifies separations based only on whether the worker is associated with a coal establishment or not.

[18] Basso et al. (2022) show that in the case of repeat events (multiple separations in our context), distributed-lag models can produce biased estimates of the dynamic response compared to the local projections estimator. Our results are qualitatively robust to using a distributed lag model.

[19] Because we cannot observe the month in which a worker leaves coal, we define the switch event as the final year in which the worker still reports earnings from the coal industry. For example, if a worker separates from a coal mining establishment in October 2016, 2016 will be defined as the "switch" event.

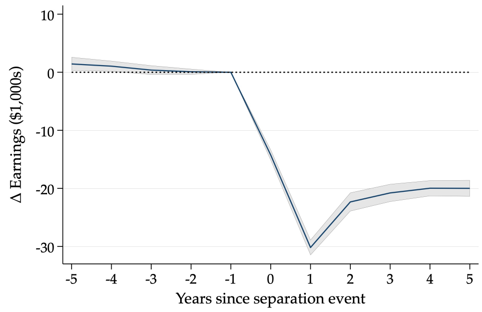
by next controlling for a vector of worker-level covariates, X'_{it} that includes worker i's age in year t, an indicator for whether the worker is male, and an indicator for whether the worker is non-Hispanic white, as well as Census region and year fixed effects, δ_r and γ_t. Finally, in our least parsimonious specification, we include worker fixed effects, α_i. In all specifications, we cluster standard errors at the commuting zone level. Our results are robust to two-way clustering at the worker- and firm-level, as well as including lagged separations in the regression to account for potential serial correlation.

Our least parsimonious specification is closest to the standard regression specification estimated in the large literature on separations that follows from the seminal contribution of Jacobson et al. (1993). We abstract from the common choice made in the literature to distinguish between "mass layoff events" from "distressed firms" and "non-distressed firms" (Jacobson et al., 1993; Von Wachter et al., 2009; Couch and Placzek, 2010; Davis and von Wachter, 2011; Fallick et al., 2021). Instead, we distinguish between coal separations and non-coal separations.

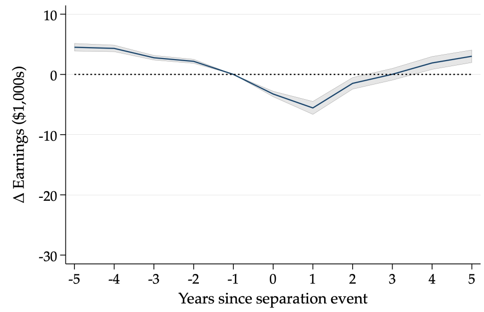
Figure 5 presents the evolution of earnings before and after coal and non-coal separations. Across all specifications, we see that earnings are quite stable in the years preceding a firm separation from coal mining. Coal separations are associated with substantial and persistent earnings losses. Workers experience an immediate decline in earnings of about $13,000 in the separation year, with unconditional losses growing to about $30,000 per year in the subsequent year and persisting at around $20,000 five years post-separation. These magnitudes are robust across specifications. In all the left panels of Figure 5, earnings fall by about $30,000 in the year immediately following relative to the year prior to the coal separation. Including worker fixed effects, suggests a more meaningful recovery, but workers still earn about $8,500 less five years following the separation event.

To put the magnitude of these losses into context, Appendix Figure A3 displays how coal separations affect cumulative, normalized earnings. Using the same specification described in equation 1, we redefine the outcome variable as cumulative earnings between year t and $t + h$, normalized by average annual earnings in the five years preceding the separation event (i.e., years $t - 1$ through $t - 5$). We find that separation from coal is as-

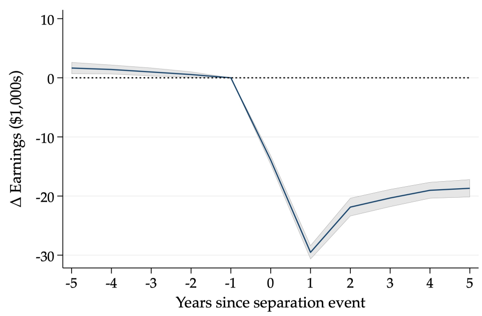
Figure 5: Separations and the Evolution of Earnings



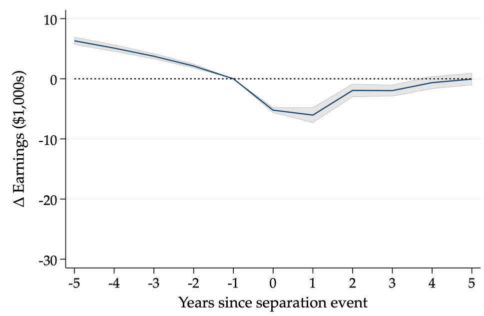
(a) Coal; no controls



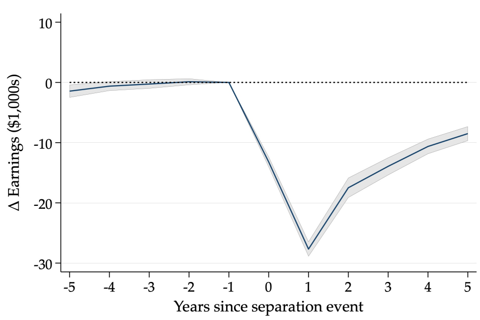
(b) Non-coal; no controls



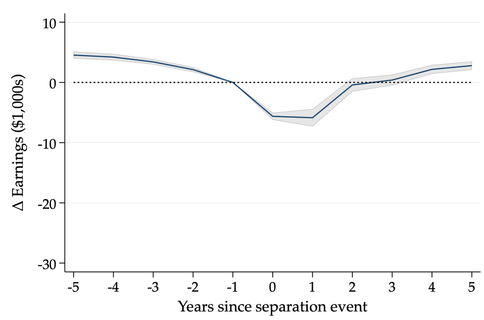
(c) Coal; basic controls



(d) Non-coal; basic controls



(e) Coal; worker FE



(f) Non-coal; worker FE

Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s, and Census Business Register. Note: This figure plots the association between a firm separation event and the evolution of earnings five years before and after the separation event. The left panels reflect separations from the coal industry, and the right panels reflect all other firm separations. The sample is limited to workers born between 1955 and 1985 with non-negative AGI and reporting non-zero earnings in years t and $t-1$. Each estimate is the result of a separate OLS regression estimated at each time horizon as specified in equation 1. The top two panels reflect the estimates from a bivariate regression between the change in earnings relative to $t-1$ and the separation event. No additional controls are included. The middle two panels reflect the estimates from a multivariate regression between the change in earnings relative to $t-1$ and the separation event, including controls for age, a dummy for being male, a dummy for being non-Hispanic white, and year and region fixed effects. The bottom two panels reflect the estimates from a multivariate regression between the change in earnings relative to $t-1$ and the separation event, including year, region, and worker fixed effects. Controls for age, sex, and race/ethnicity are collinear with individual and year fixed effects and so are not included. Shading reflects 95 percent confidence interval. Standard errors are clustered at the Commuting Zone.

sociated with a reduction of two years' worth of pre-separation earnings five years after the separation.

We emphasize that these results are descriptive. We do not ascribe a causal interpretation because separations may be voluntary. Workers might leave the industry for better job opportunities elsewhere, introducing an upward bias in the relationship between separation and subsequent earnings (Topel and Ward, 1992; Brown et al., 2006; Haltiwanger et al., 2018). Alternatively, when workers are laid off, the decision to lay one worker off rather than another may be correlated with factors that shape their future earnings potential resulting in a downward bias. This is one of the primary reasons that "mass layoff events" are used to identify the causal effects of separations, albeit for a selected sample of firms and workers.

In the right panels of Figure 5 we see that non-coal separations are associated with more muted changes in earnings. Across specifications, we estimate a decline in earnings in the lead-up to a separation event. Following separation, we see an initial $6,500 reduction in earnings, which is recovered within five years. This pattern is robust across specifications. These estimates reflect the average effect of voluntary and involuntary separations and cover the great recession, involuntary separations would have been more frequent. Part of the reduction in earnings could reflect the loss of firm- or industry-specific human capital, which workers may voluntarily accept if they believe they will earn more in the long run. Looking at cumulative, normalized earnings we see that non-coal separations are associated with earnings growth, consistent with the idea that workers move up a "job ladder" to better jobs by conducting on-the-job searches and accepting better job offers (Topel and Ward, 1992; Hahn et al., 2021).

While we do not distinguish between "non-distressed" and "distressed" firms, the juxtaposition of separations from coal and non-coal reveals a similar pattern to the separations literature more broadly. For example, in the seminal paper by Jacobson et al. (1993) the authors estimate large and persistent reductions in earnings following "mass layoff events" and smaller and insignificant effects for "non-distressed firms". While we do not ascribe a causal interpretation to our findings, we consider this descriptive evidence as providing a priori evidence that the decline of coal may have led to substantial earnings losses for coal workers. Even if the estimated effects were to reflect causal estimates, separations are discrete events with immediate earnings consequences. The decline in coal over our period of analysis was an ongoing process and there are many margins of adjustment that affected workers. The remainder of the paper explores these considerations.

4 Quasi-experimental Evidence

In this section, we leverage the fact that the decline of coal since 2011 was largely driven by plausibly exogenous technological changes in natural gas extraction, which led to a substantial decline in demand for coal (Kolstad, 2017; Linn and McCormack, 2019; Coglianese et al., 2020; Davis et al., 2022). By focusing on this broader decline, rather than separation events, we are able to examine the broader consequences of the decline of coal on workers over a longer time horizon and provide a more systematic evaluation of worker-level responses.

4.1 Research Design

Our research design is inspired by Autor et al. (2014) who evaluate the worker-level consequences of rising import penetration. By focusing on the source of the shock rather than individual separation events we are able to evaluate the importance of adjustment margins within workers' "pre-decline" firm, between firms within coal, between industries, between labor markets, and through transfers. This provides a more comprehensive understanding of workers' responses to the coal industry's decline.

The core idea is to compare workers who are ex-ante observationally similar, but have varying attachment to the coal mining industry in the pre-shock period, and thus varying exposure to the subsequent, plausibly exogenous, macroeconomic decline in coal demand. The main identifying assumption required for a causal interpretation is conditional independence. There are two components to this. First, after accounting for differences in a rich set of observable worker characteristics, we assume that workers with more tenure in the coal industry during the pre-shock period have the same earnings and employment potential as workers with less or no tenure in the coal industry. Second, we assume that any observed differences in earnings and employment trajectories between 2012 and 2019 can be attributed to the decline of coal.

Regarding the first assumption, there are several potential concerns, which we attempt to address. Our primary "treatment" definition classifies workers as "treated" if they had tenure at coal mining establishments in the five years prior to the start of coal's decline (2007–2011).[20] These workers are more attached to the industry, and therefore arguably more exposed to the coal shock that followed. Our primary control group contains all workers with less than five per-shock years of experience including workers with no attachment to coal. One may be concerned about the inclusion of partially treated workers in the control group. While less attached to coal than those with a longer tenure, these workers likely experience at least some of the resulting employment and earnings consequences. We argue this is not a major concern. The vast majority of workers in our primary control group have no attachment to the coal industry in the pre-shock years and our findings are robust to excluding these workers. Alternatively, one may be concerned that while we are able to control for a rich set of individual-level characteristics (the worker's age, an indicator for being non-Hispanic white, an indicator for being male, the log of average annual wages between 2007 and 2011, the interaction of average wages with the worker's age, the change in average annual wages between 2007 and 2011, the number of years the worker worked at their 2011 firm between 2007 and 2011, and 8 bins of establishment size), there remains unobservered heterogeneity between coal workers and non-coal workers that we aren't able to adjust for. In Appendix B.1 we document that our findings are not sensitive to the inclusion or omission of individual controls. Our findings are also robust to controlling for the number of years in which a worker worked for their 2011 industry over the 2007–2011 period and to restricting comparisons between workers with more vs. less coal experience, omitting non-coal workers completely. We

[20]Our results are not sensitive to using the longer set of pre-shock years (2005-2011) to characterize workers as most attached to coal, or to using more conservative definitions of "full time" employment based on annual earnings cutoffs.

also consider alternative definitions of exposure, including a continuous parameterization of attachment to coal and using a set of binned variables, where each bin represents the number of pre-decline years a worker's primary employer was a coal mining establishment. Our findings remain robust to these alternative exposure definitions. Further details can be found in Appendix B.4.

Even if one is willing to assume that workers with more tenure in the coal industry during the pre-shock period have the same earnings and employment potential as workers with less or no tenure in the coal industry, one still has to be willing to attribute any differential changes in outcomes to the decline of coal. We have to assume that there are no other aggregate changes that differentially affect more vs. less exposed coal workers. Given the spatial concentration of coal mining activities, a concern here is that other "non-coal" shocks could differentially affect workers. For example, if coal-rich regions were differentially less likely to recover from the Great Recession, then our estimates would reflect the combined effect of both the Great Recession and the decline of coal (Yagan, 2019). Alternatively, if non-coal workers were differentially less likely to recover from the Great Recession this would attenuate any adverse consequences from the decline of coal. The labor markets most affected by the Great Recession — Sun Belt states including California and Florida, and Rust Belt states including Michigan and Indiana — do not overlap with regions in which coal is concentrated, suggesting that coal regions may have been less affected by the Great Recession. Indeed, unlike many other tradable industries, coal mining experienced a small uptick in employment during the Great Recession. While we can't rule out the empirical relevance of this concern, we show that our findings are robust to including more detailed geographic controls, e.g., state fixed effects, as well as controlling for local economic conditions. As noted above, our conclusions are also robust to restricting comparisons between more vs. less exposed coal workers, omitting non-coal workers from the analysis. This within-coal analysis leverages heterogeneity in exposure within coal regions, meaning that workers would be more likely to experience common exposure to non-coal macroeconomic changes. It is reasonable to consider that the

An additional identification assumption is that the decline of coal didn't indirectly affect non-coal workers. Given the spatial concentration of coal, reductions in labor demand could result in less local demand, affecting non-coal workers in the same labor market. In Appendix Section B.3, we show that our findings are robust to including an additional control variable that captures a worker's spatial proximity to local coal shocks in other labor markets. Our findings are also robust to excluding "pre-shock" non-coal workers that are in coal communities.

4.2 Empirical Specification

As described in section 2, our baseline quasi-experimental analysis sample contains all age-restricted workers with some connection to coal, and a 10-percent random sample of age-restricted non-coal workers who responded to the ACS in 2010. All workers were employed "full-time" in each year between 2007 and 2011. Our main analysis estimates the following specification:

$$E_{i\tau} = \beta_0 + \beta_1 \mathbb{1}[Coal_{i,2007\text{-}11}] + X_{i,0}^{'}\gamma + \delta_r + \varepsilon_{i\tau} \tag{2}$$

where $E_{i\tau} = \sum_{t=2012}^{t=2019} \frac{E_{it}}{\overline{E}_{it_0}}$ reflects the cumulative earnings of worker i between 2012 and 2019, normalized by their average annual earnings between 2007 and 2011, $\overline{E}_{it_0}$. This measure of cumulative earnings captures the entirety of a worker's labor market activity following the coal shock. By normalizing this value to pre-shock earnings $\overline{E}_{it_0}$, we observe how exposure to the shock influences the evolution of a worker's earnings. We also examine additional outcome variables: the cumulative number of years employed between 2012 and 2019, cumulative earnings per year employed between 2012 and 2019 (again, normalized by average annual earnings between 2007 and 2011), and measures of geographic mobility, social insurance participation, and retirement income. $\mathbb{1}[Coal_{i,2007\text{-}11}]$ is a binary variable equal to one if worker i's primary employer was a coal mining establishment in all five of the pre-shock years (2007-2011), and zero otherwise. The coefficient of interest is β_1 captures the difference in outcomes between coal workers with more vs. less attachment to the coal industry during the pre-shock period. $X_{i,0}^{'}$ captures a rich set of worker-level controls, including the worker's age, an indicator for being non-Hispanic white, an indicator for being male, the log of average annual wages between 2007 and 2011, the interaction of average wages with the worker's age, the change in average annual wages between 2007 and 2011, the number of years the worker worked their 2011 firm between 2007 and 2011, and 8 bins of establishment size (based on 2011 establishment). We also include Census region fixed effects, δ_r. We cluster standard errors on the worker's firm, as measured in 2011, to allow for correlation in the error terms among workers who are initially employed in the same firm.[21]

4.3 Results

Table 2 presents our main results, reflecting the association between "exposure to the decline of coal" and cumulative earnings (column 1), the number of years with positive earnings (column 2), and earnings per year (column 3).

We estimate that greater "pre-shock" exposure to the coal industry is associated with sizeable earnings losses between 2012 and 2019. The most exposed coal workers lost an additional year and a half (1.597) of their pre-shock (2007-2011) average annual earnings relative to observationally similar workers with less or no "pre-shock" exposure (column 1).[22] The negative coefficients in columns 2 and 3 indicate that this cumulative earnings effect stems from both fewer years of employment (the extensive margin) and lower earnings when employed (the intensive margin). We estimate that, on average, more exposed coal workers had 0.37 fewer years of work between 2012 and 2019 compared to the control group (column 2), and experienced 17.4 percent lower earnings during the years that they were employed (column 3).[23]

[21]Results are also robust to clustering standard errors at the level of a worker's 2011 commuting zone, to allow for correlation in the error terms among workers who are initially employed in the sample labor market.

[22]As noted in section 4.1, our findings are robust to a broad range of sensitivity analyses and robustness tests. In appendix B.1 we document that these findings are not sensitive to the inclusion or omission of individual controls. In Appendix Sections B.3 and B.4, we show that controlling for a worker's industry tenure, controlling for CZ-level exposure to spatially proximate coal shocks, and exploiting different definitions of exposure to coal's decline yield similar conclusions to our main results. Our conclusions are also robust to using alternative samples and control groups.

[23]We are not able to distinguish whether earnings reductions result from fewer working hours or lower

Table 2: Exposure to coal shock and the evolution of earnings, 2012-2019

	(1) Cumulative earnings	(2) # of years w/ earnings >0	(3) Earnings per year employed
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.597*** (0.087)	-0.370*** (0.037)	-0.174*** (0.010)
Outcome mean (SD)	8.05 (3.71)	7.45 (1.43)	1.06 (0.43)
Controls	✓	✓	✓
Region FE	✓	✓	✓
Observations	152,000	152,000	152,000

Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register. Notes: The outcome variables are defined over the 2012 to 2019 period. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Sample sizes are rounded per Census disclosure rules. Column 1 and 2 have the same number of underlying observations. There are slightly fewer observations in column 3 because the outcome variable is not observed for workers who are never employed between 2012 and 2019. Robust standard errors in parentheses are clustered on the worker's firm in 2011. *** $p<0.001$, ** $p<0.01$, * $p<0.05$

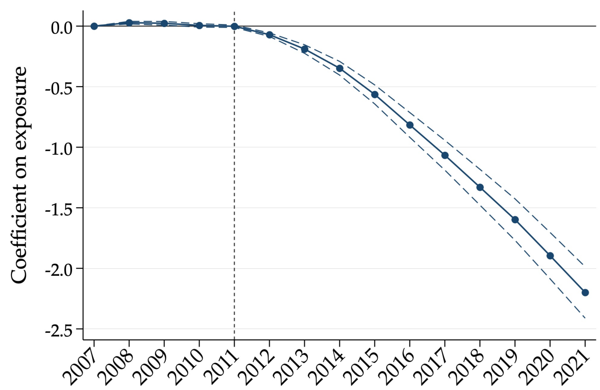
The magnitude of these effects is substantial. Autor et al. (2014) estimate that workers at the 75th percentile of import penetration experienced nearly a half-year reduction in cumulative earnings compared to a worker at the 25th percentile of import penetration exposure. They estimate no effect on total employment. Reductions in earnings are driven by a 2.6% reduction in earnings per year of employment. Walker (2013) estimates that manufacturing workers affected by the introduction of the Clean Air Act experienced an initial reduction in earnings before a return to trend within 7 years. While not directly comparable, the differences in magnitude and mechanism (we estimate reductions in both years of employment and earnings per year of employment) are consistent with the premise that regionally concentrated labor demand shocks may have larger effects on workers.

To examine the temporal dynamics of these effects over the course of coal's decline, we estimate separate regressions over varying time horizons from 2007 to 2021, reflecting

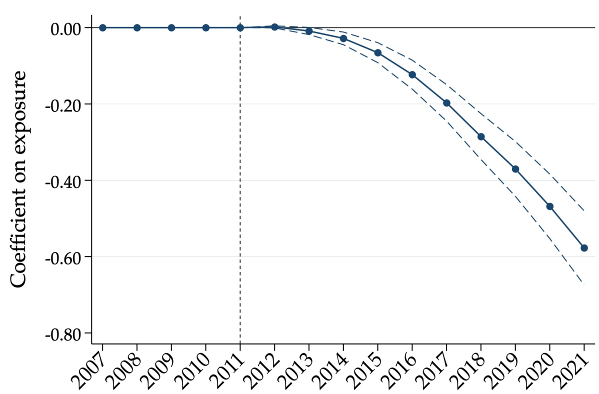
hourly wages.

the cumulative effect up to that point in time. The estimate for 2019 is reflected in Table 2.

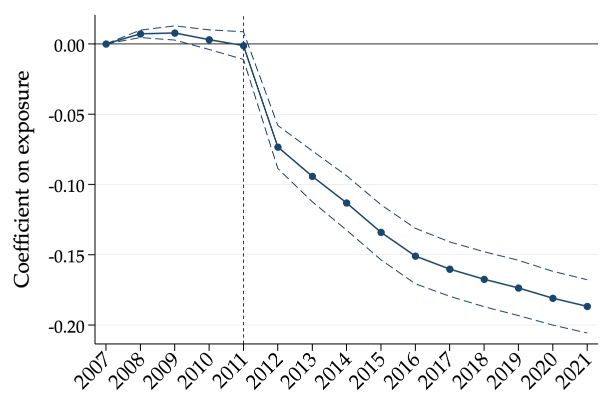
Figure 6: Extensive and intensive margin changes



(a) Cumulative earnings



(b) Cumulative employment



(c) Earnings per year employed

Note: Figure plots the regression coefficients and 95% confidence intervals from separate regressions of cumulative earnings (Figure 6a) cumulative employment (Figure 6b) or earnings per year employed (Figure 6c) over the specified time period. In years prior to 2012, the outcome is defined over the year indicated on the x-axis and 2011. In years 2012–2021, the outcome is defined over the period between 2012 and the year indicated on the x-axis. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s, and Census Business Register.

Panel a) of Figure 6 indicates that cumulative earnings for exposed coal workers are relatively stable compared to observationally similar workers in the years leading up to coal's decline. Beginning in 2012, the cumulative earnings losses for more exposed coal workers steadily grow. The accumulation of losses does not diminish at any point during our sample period. In Panel b) we see that reductions in employment are relatively minimal during the initial years of coal's decline, but grow progressively more negative over time. As with cumulative earnings, we see little evidence of recovery. In Panel c) we see, in contrast to the employment response, that earnings conditional on employment drop sharply in 2012, followed by a progressive decline over time that starts to level off by the end of the sample period. On average, exposed coal workers appear to remain relatively attached to the labor force in the initial years of coal's decline, but receive lower earnings. Over time, workers exit the labor force at increasing rates. These two forces — a sharp drop in earnings during years of employment and a slow, but progressive decline in attachment to the workforce — combine to generate the relatively linear decline in cumulative earnings losses.

4.3.1 The role of reallocation

Our main findings suggest that the decline of coal resulted in substantial reductions in earnings and employment. It is important, however, to understand the extent to which worker-level adjustments may have mitigated the consequences for some workers, providing insights into where in the adjustment process frictions may impede workers, and which types of workers are most affected.

In Table 3 we present the results of an analysis decomposing the average worker-level effects of the decline of coal (Table 2) into a set of additive, mutually exclusive channels that include employment observed at the worker's initial employer (column 2); employment at other firms within the worker's 2011 industry (column 3); and employment outside of the worker's 2011 industry, including non-employment (column 4). This analysis captures the direct effect of coal's decline on workers' tenure and earnings at their initial employers as well as any subsequent, potentially offsetting effects of moves across employers, within and outside of the coal mining sector.

These categories are exhaustive of all possible forms of employment, such that the coefficient estimates in columns 2, 3, and 4 of Panels A and B sum to the coefficient estimate in column 1 of the corresponding panel. The estimates in Panel C are not additive (earnings per year employed), because the outcome variable is not observed in years in which a worker does not report any earnings in a given category. The estimates in column 1 correspond to our main results presented in Table 2.

Table 3: Exposure to coal shock and the evolution of earnings by employer and industry

	(1)	(2)	(3)	(4)
	All employers	**Same industry**		**Diff. industry**
		Same firm	Diff. firm	
Panel A: Cumulative earnings				
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.597***	-0.213	0.302*	-1.687***
	(0.087)	(0.190)	(0.149)	(0.108)
Outcome mean (SD)	8.05 (3.71)	4.03 (3.77)	1.46 (2.79)	2.55 (3.79)
Panel B: Cumulative employment				
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.370***	0.166	0.572***	-1.108***
	(0.037)	(0.198)	(0.154)	(0.097)
Outcome mean (SD)	7.45 (1.43)	3.66 (3.02)	1.34 (2.23)	2.45 (2.80)
Panel C: Earnings per year of employment				
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.174***	-0.123***	-0.161***	-0.307***
	(0.010)	(0.012)	(0.012)	(0.019)
Outcome mean (SD)	1.06 (0.43)	1.07 (0.35)	1.04 (0.50)	0.98 (0.59)
Controls	✓	✓	✓	✓
Region FE	✓	✓	✓	✓
Obs. (Panels A and B)	152,000	152,000	152,000	152,000
Obs. (Panel C)	152,000	122,000	55,000	85,000

The outcome variables are defined over the 2012 to 2019 period. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Column 1 shows aggregate effect on cumulative earnings and employment. Columns 2–4 decompose these effects into employment and earnings obtained at the worker's 2011 employer versus other employers, and within versus outside of the worker's 2011 industry, defined at the 2-digit NAICS code. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** $p<0.001$, ** $p<0.01$, * $p<0.05$

Panel A of Table 3 reveals that cumulative earnings losses for workers most exposed to the coal shock are predominantly driven by employment outside of the mining sector.

Exposed coal workers suffer earnings losses equivalent to approximately 1.7 years of pre-shock annual earnings when outside of mining. These losses are marginally offset by increased earnings from working at different firms within the mining sector. Panel B exhibits a similar pattern for employment duration, with losses driven by years in which exposed workers are observed outside of mining. Exposed workers spend 1.1 fewer years employed outside of their initial industry than observationally similar workers over the 2012–2019 period. This extensive margin effect is large, representing a 45 percent decline compared to the sample mean (2.45 years of employment in different industries). While extensive margin responses are driven by years spent outside of mining, Panel C reveals that exposed coal workers experience reduced earnings per year of employment across firms and industries. Workers experience a 12 to 16 percent reduction in earnings per year of employment within their initial industry. However, in years in which exposed coal workers are employed in different industries, they suffer much larger earnings losses, on the order of 30 percent per year employed. These findings are consistent with the descriptive evidence presented by Colmer et al. (2022), which suggests that workers in all legacy energy sectors may face substantial wage penalties when working outside of their initial industry.[24]

One advantage of our data is that we are able to track workers' locations throughout the study period, including during years of non-employment. In Table 4, we examine how relocation across labor markets and industry may interact to influence losses. We decompose the total worker-level effect of coal shock exposure (column 1) into total earnings or years of employment observed within the worker's 2011 CZ and 2011 industry (column 2), total earnings or years of employment observed within the 2011 CZ but in a different industry (column 3), total earnings or years of employment observed in a different CZ but within the same industry (column 4), and total earnings or years of employment observed outside of the worker's 2011 CZ and industry. In Appendix B.2, we analyze the effect of exposure to the coal shock on various dimensions of geographic mobility. We

[24]In Appendix B.5 we dig deeper into the type of industries that workers move into. We show that entering other "high-wage" industries does not attenuate losses. In fact, losses are higher in these industries. Such transitions are rare and may suggest workers move down the job ladder, working in lower-wage occupations within these "high wage" industries.

find that more exposed coal workers are not less likely to move across labor markets than workers in the control group.

Table 4: Exposure to coal shock and the evolution of earnings by sector and CZ

	(1)	(2)	(3)	(4)	(5)
	All	**Same CZ**		**Different CZ**	
		Same ind.	Diff. ind.	Same ind.	Diff. ind.
Panel A: Cumulative earnings					
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.597***	0.070	-1.351***	0.020	-0.336***
	(0.087)	(0.104)	(0.097)	(0.026)	(0.023)
Outcome mean (SD)	8.05 (3.71)	4.99 (3.89)	2.06 (3.39)	0.51 (1.87)	0.49 (1.90)
Panel B: Cumulative employment					
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.370***	0.637***	-0.899***	0.101***	-0.208***
	(0.037)	(0.113)	(0.087)	(0.023)	(0.019)
Outcome mean (SD)	7.45 (1.43)	4.57 (3.03)	2.00 (2.61)	0.43 (1.39)	0.45 (1.40)
Panel C: Earnings per year of employment					
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.174***	-0.134***	-0.302***	-0.162***	-0.336***
	(0.010)	(0.010)	(0.021)	(0.012)	(0.015)
Outcome mean (SD)	1.06 (0.43)	1.06 (0.36)	0.97 (0.58)	1.11 (0.58)	1.02 (0.71)
Controls	✓	✓	✓	✓	✓
Region FE	✓	✓	✓	✓	✓
Obs. (Panels A and B)	152,000	152,000	152,000	152,000	152,000
Obs. (Panel C)	152,000	132,000	75,500	19,500	19,500

The outcome variables are defined over the 2012 to 2019 period. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Column 1 shows aggregate effect on cumulative earnings and employment. Columns 2–5 decompose these effects into employment and earnings obtained in the 2011 CZ of residence versus other CZs, and within versus outside of the worker's 2011 industry, defined at the 2-digit NAICS code. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** $p<0.001$, ** $p<0.01$, * $p<0.05$

The coefficients in Table 4 provide a nuanced assessment of how sectoral and geographic mobility interact to shape the earnings and employment trajectories of workers exposed to the coal shock. Consistent with our findings in Table 3, we observe that earnings and employment losses for exposed coal workers are primarily driven by years spent outside their initial industry, irrespective of their geographic location. The estimates in Panel A indicate that about 85 percent of cumulative earnings losses are driven by years in which workers are not employed in mining but still reside in their initial labor market. However, relative to the sample means, the coefficient estimates reveal that, conditional on switching industries, exposed coal workers experience large relative earnings losses across labor markets. This is driven by both reductions in years of employment and reductions in earnings per year of employment. Estimates in Panel B reveal that exposed coal workers spend about 0.9 fewer years employed outside of their initial industry in their initial commuting zone, and about 0.2 fewer years employed outside both their initial industry and commuting zone. The average employment duration in the same CZ but a different industry (2 years) is more than four times that in both a different CZ and industry (0.45 years). This suggests that the extensive margin response is proportionally similar across labor markets when accounting for baseline employment patterns.

While non-employment contributes significantly to cumulative earnings losses, we find that earnings reductions during periods of employment also play a crucial role. Panel C demonstrates that exposed coal workers suffer annual earnings declines across all industry-location pairs. The reduction in earnings per year employed in a different industry, however, is more than double the reduction in earnings per year employed within their initial industry. This holds true regardless of geographic location. That aggregate losses are driven by years in which workers remain in their 2011 CZ but are not employed in their initial industry may reflect limited alternative employment opportunities in many coal communities. However, the substantial losses — especially in relative terms — observed when workers relocate to different CZs suggest that barriers to geographic mobility are unlikely the sole friction impeding workers' ability to adjust. Although movers likely differ from non-movers in ways endogenous to expected outcomes, these estimates imply that, on average, geographic mobility does not attenuate the earnings and employment losses of workers exposed to the coal shock. Conditional on staying in or switching industries, former coal workers experience similar earnings losses whether they remain in or leave their initial CZs.[25]

Our findings suggest that relocating to different labor markets is insufficient to mitigate cumulative losses. Instead, our evidence is most consistent with the presence of firm- or industry-specific skills that are not transferable, or valued less, in other settings (Neal, 1995).

4.4 The role of alternative sources of income

As exposed workers experience earnings and employment declines, their income composition may shift towards alternate sources to supplement lost wages. A large body of literature has documented that declining labor market opportunities often lead to increased reliance on Social Security Disability Insurance (SSDI) and other forms of government assistance (Black et al., 2002; Autor et al., 2003, 2013, 2014; Charles et al., 2018). While we do not directly observe SSDI receipt, we proxy for it using receipt of any Social Security benefits, defined as having received a form SSA-1099. This will occur if the individual received any retirement, survivor, or disability (SSDI) benefits. Given that our sample is born between 1955 and 1985, workers will be at most 64 by the end of the outcome period (2019) and thus most workers will be below the minimum age for Social Security retirement benefits (62), suggesting that SSA-1099 receipt almost certainly indicates SSDI for the majority of our sample. Of course, declining employment opportunities may induce early retirement, and thus we explore the effect of coal shock exposure on the receipt of Social Security benefits separately for individuals born 1960 or later, such that they are less than 60 by the end of the outcome period. We additionally explore how exposure to the coal shock affects retirement withdrawals from IRA/401k accounts and pension contributions, based on form 1099-R, in Appendix B.7.

Table 5 presents our findings on the relationship between exposure to the coal shock and various transfer sources. Columns 1 and 2 report estimates for the association be-

[25] In Appendix B.6, we explore whether workers fare differently based on the degree to which their industries are dependent on local demand. We estimate that reductions in earnings per year of employment are much larger in non-tradable, construction, and other industries compared to tradable industries. However, we do not see meaningful differences within industrial categories between labor markets suggesting that fewer local opportunities due to reductions in local demand are unlikely to be a major driver of losses.

Table 5: Exposure to coal shock and receipt of SSA/self-employment income, 2012-2019

	(1)	(2)	(3)	(4)	(5)	(6)
	# of years SSA-1099 >0		Cumulative 1040 SS income		# of years self-emp. (1040) >0	
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	0.368***	0.196***	0.078***	0.039***	-0.293***	-0.286***
	(0.030)	(0.018)	(0.010)	(0.005)	(0.023)	(0.021)
Outcome mean (SD)	0.30 (1.12)	0.14 (0.80)	0.16 (0.62)	0.08 (0.43)	0.74 (1.71)	0.75 (1.69)
Controls	✓	✓	✓	✓	✓	✓
Region FE	✓	✓	✓	✓	✓	✓
Sample	all	born 1960-	all	born 1960-	all	born 1960-
Observations	152,000	123,000	152,000	123,000	152,000	123,000

The outcome variables are defined over the 2012 to 2019 period. In columns 1 and 2, the outcome variable is defined as the number of years between 2012 and 2019 in which the worker reported any SSA-1099 income. In columns 3 and 4, the outcome variable is defined as the cumulative reported income from 1040 Social Security. In columns 5 and 6, the outcome variable is defined as the number of years between 2012 and 2019 in which the worker filed any self-employment (1040) income. In even-numbered columns, the sample is restricted to workers born on or after 1960. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** p<0.001, ** p<0.01, * p<0.05

tween coal decline exposure and years of SSA-1099 receipt between 2012–2019. The most exposed workers report 0.37 additional years of SSA-1099 receipt compared to observationally similar workers (column 1). This effect declines to 0.20 years when restricting to workers born in 1960 or later to avoid the influence of early retirement decisions (column 2), but remains substantial at over 100% of the sample mean. Appendix Figure A4, illustrates the dynamics of SSA-1099 receipt. Initially, there is no notable increase, but the gap in SSA receipt grows progressively larger, mirroring the inverse of the employment dynamics shown in Figure 6b. In each time horizon, the point estimate for cumulative years of employment (Figure 6b) is almost exactly offset by the point estimate for cumulative years of SSA-1099 income (Figure A4).

In columns 3 and 4 of Table 5, we explore how exposure to the coal shock influences total tax-unit level Social Security income from form 1040.[26] We estimate that more exposed coal workers receive an additional 0.078 years' worth of earnings in Social Security

[26]Unlike receipt of a SSA-1099 form, which is defined at the worker level, Social Security income on form 1040 is defined at the household level. This would include, for example, a retired spouse's retirement income, and thus we can be less certain that this measurement includes only SSDI income.

income compared to similar workers over 2012–2019 (column 3), declining to 0.04 years (or about a 50 percent increase over the sample mean) for the younger cohort (column 4). These findings suggest that coal workers may be able to recoup a modest portion of their earnings losses through what are arguably "second-best" transfer mechanisms. This implies that there may be fiscal benefits to identifying lower-cost interventions that help smooth the transitional costs of the decline of coal. For instance, Hyman et al. (2024) show that wage insurance provisions in the U.S. Trade Adjustment Assistance Act, which support workers for whom re-training is ineffective, infeasible, or unavailable, increase short-run employment probabilities and long-run cumulative earnings.

In the final two columns of Table 5, we explore how coal shock exposure influences the receipt of self-employment (as reported on Schedule SE of form 1040) income. We estimate that exposed workers report 0.29 fewer years of self-employment over the 2012 to 2019 period, a 40 percent decline relative to the sample mean. This may reflect the relative skills of exposed coal workers, which may translate poorly to various forms of self-employment, or the labor markets in which coal is concentrated, which may be less amenable to successful self-employment activities. Either case is consistent with the previously documented findings, which indicate that coal workers most exposed to the recent coal shock do not smoothly transition to alternative employment opportunities outside of the industry.

5 Conclusion

After its contemporary peak in 2011, U.S. coal mining employment fell dramatically, largely driven by the changing price of natural gas relative to coal. This coal shock offers a unique lens through which to examine the labor market consequences of a changing energy landscape and a regionally concentrated labor demand shock. By leveraging comprehensive administrative data on the universe of coal workers between 2005 and 2021, we provide systematic evidence on the worker-level consequences of, and responses to, the decline of coal in the United States.

Workers most exposed to the coal shock experienced substantial losses between 2012 and 2019, with cumulative earnings declining by more than a year's pre-shock wages due to both reductions in years of employment and lower earnings when employed. Unlike the labor market adjustment documented in other settings, non-employment emerged as an important margin of adjustment. Decomposing these effects across firms, industries, and geographies, we find that reallocation across industries and labor markets does not mitigate these adverse consequences. Exposed workers, only marginally less geographically mobile than their counterparts, face significant employment and earnings reductions both within and outside their initial labor markets. They struggle to transition to other industries, even comparably high-paying ones, and earn substantially less when they do, suggesting that skill mismatch rather than spatial mismatch may be the primary factor influencing earnings losses. Finally, we show that exposed workers partially offset their earnings losses through increased reliance on transfer payments like SSDI.

The recent decline in demand for coal provides a preview of the disruption that future contractions in demand for fossil fuels may cause for workers in carbon-intensive sectors. The clean energy transition is poised to reduce demand for fossil fuels, as well as products from carbon-intensive industries, both of which have historically provided high wages in relatively isolated labor markets offering few alternative employment opportunities. When workers are not able to remain attached to the industries in which they might have developed firm- or industry-specific skills (Neal, 1995), the transitional costs appear to be substantial. The results in this paper are consistent with the presence of relatively large labor market frictions that prevent smooth adjustment. While both skill and geographic mismatch may play important roles in influencing workers' earnings and employment trajectories, our findings suggest that skill mismatch may be a more important friction. Understanding the extent to which such frictions can be alleviated remains an important area for future research.

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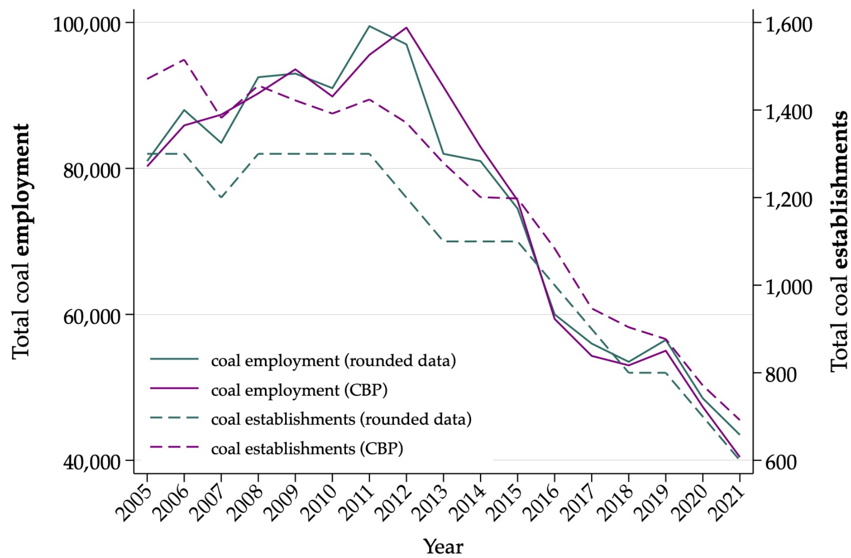
Appendix

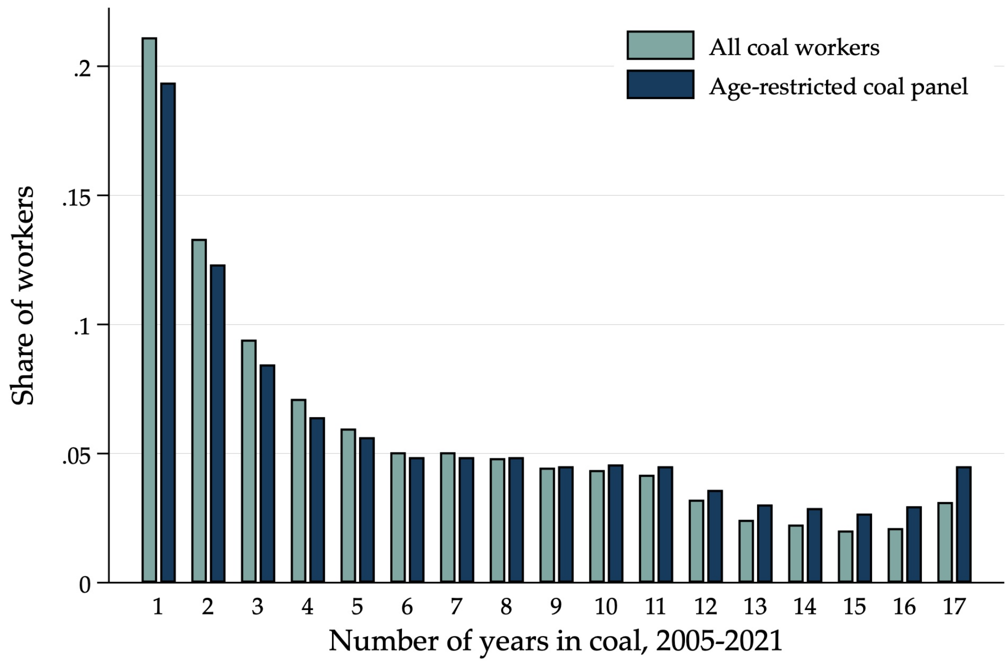
A Appendix Figures

Figure A1: Coal establishments & employment, 2005–2021, administrative data versus CBP data



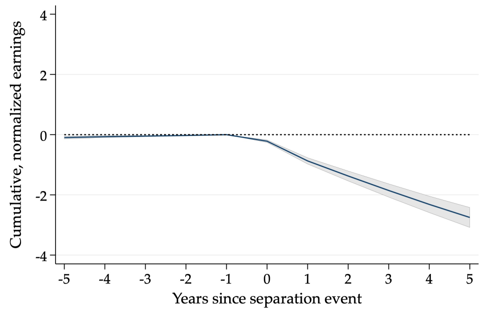
Note: This figure shows the total number of coal mining establishments (on the left axis) and total coal mining employment (on the right axis) between 2005 and 2021, separately based on the (rounded) administrative data used in this paper and based on the publicly available data from the CBP. Workers are identified as coal miners if their primary employer (in terms of total earnings) in a given year was a coal mining establishment. Coal mining establishments are defined as those with NAICS codes 2121 and 213113. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s, Census Business Register, and County Business Patterns database.

Figure A2: Number of years worked in coal, 2005–2021

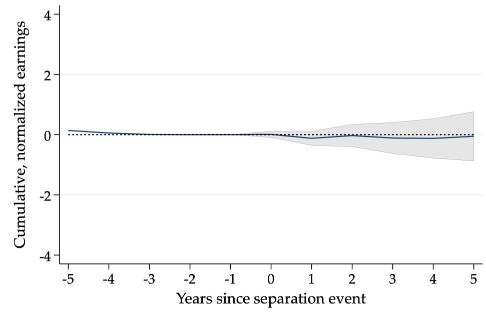


Note: The value on the X-axis indicates the number of years a worker's primary earnings were drawn from the coal mining industry between 2005 and 2021. All coal workers refers to all workers whose primary earnings were drawn from the coal mining industry in any year over the 2005–2021 period. The age-restricted coal panel further restricts this sample to individuals born between 1955 and 1985. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s, and Census Business Register.

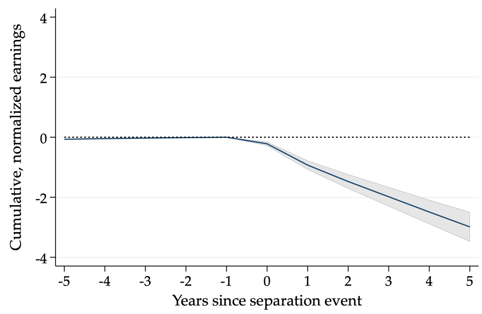
Figure A3: Separations and the Evolution of Cumulative, Normalized Earnings



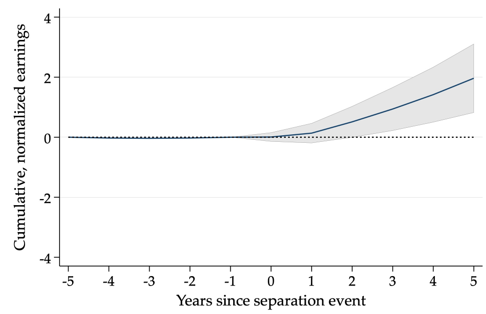
(a) Coal; no controls



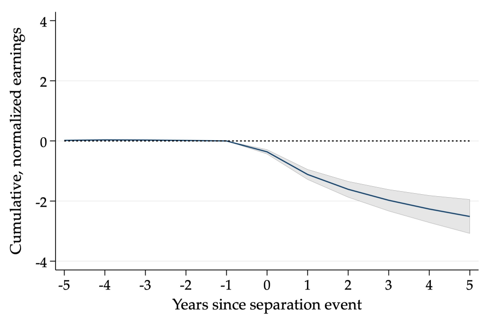
(b) Non-coal; no controls



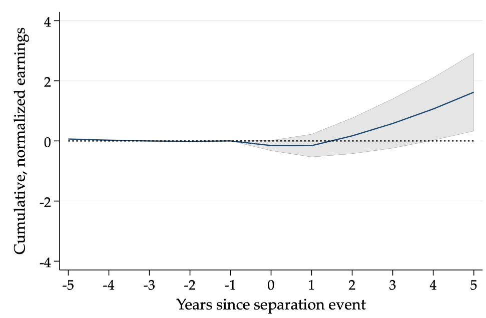
(c) Coal; basic controls



(d) Non-coal; basic controls



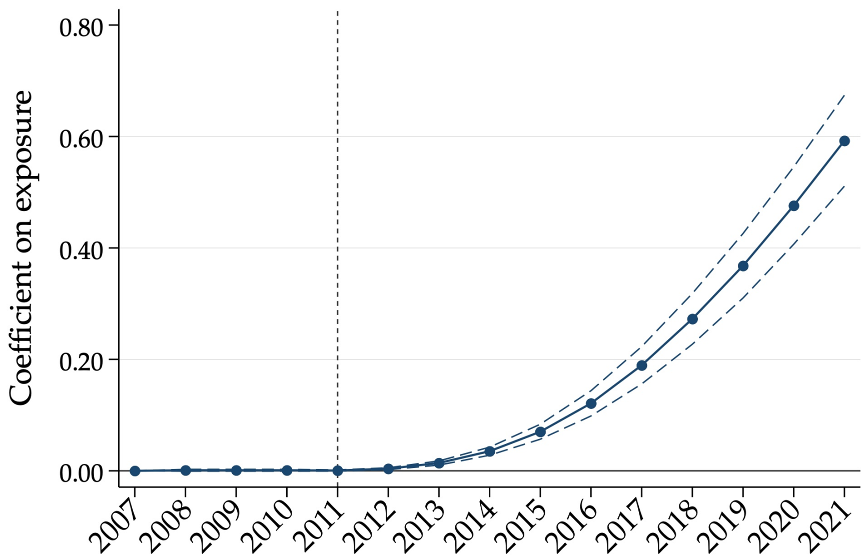
(e) Coal; worker FE



(f) Non-coal; worker FE

Note: This figure plots the bivariate relationship between a firm separation and the evolution of cumulative, normalized earnings five years on either side of the separation event. The outcome for years $t \geq 0$ is the sum of earnings between years t and the year on the x-axis, divided by $t-5$ through $t-1$ average earnings. The outcome for years $t < -1$ is the sum of earnings between years $t-2$ and the year on the x-axis, divided by average earnings in years $t-5$ through $t-1$. The left panels reflect separations from coal establishments, and the right panels reflect all other firm separations. The sample is workers born between 1955 and 1985 with non-negative AGI and reporting non-zero earnings in years t and $t-1$. Each estimate is the result of a separate bivariate regression estimated for each time horizon as presented in equation 1. The top two panels include no controls. The middle two panels control for age, a dummy for being male, a dummy for being non-Hispanic white, and year and region fixed effects. The bottom two panels include year, region, and worker fixed effects. Shading reflects 95 percent confidence interval. Standard errors are clustered at the Commuting Zone. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s, and Census Business Register.

Figure A4: Cumulative number of years receiving SSA-1099, 2007–2021



Note: Figure plots the regression coefficients and 95% confidence intervals from separate regressions of the number of years the worker received SSA-1099 income over the specified time period. In years prior to 2012, the outcome is defined over the year indicated on the x-axis and 2011. In years 2012–2021, the outcome is defined over the period between 2012 and the year indicated on the x-axis. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s, and Census Business Register.

B Margins of adjustment: Robustness and extensions

B.1 Sensitivity to controls

Table B1 displays the sensitivity of the coefficient estimates in Table 2 to the inclusion of controls. We initially omit all controls and fixed effects to display the unconditional variation in the data. In column 2, we include region fixed effects; column 3 additionally controls for basic demographic characteristics — age, an indicator for being non-Hispanic white, and an indicator for being male; column 4 further controls for firm tenure and the change in average wages in the pre-shock period; finally, column 5 controls for pre-shock wages and their interaction with age. Each additional set of controls modestly reduces the magnitude of the point estimate in Panels A and B (cumulative earnings), while the coefficient in Panel B (cumulative employment) is relatively stable across specifications. The estimated coefficient for cumulative earnings in the least parsimonious specification is 27% smaller in magnitude than the estimate without controls. Overall, our findings are not especially sensitive to the inclusion of controls.

B.2 Geographic mobility

In Table B2, we explore the consequences of exposure to the coal shock on geographic mobility. The outcome in column 1 is defined as the cumulative number of years between 2012 and 2019 that a worker lived in his or her 2011 CZ. The outcome in column 2 is defined analogously but considers the number of years spent in the same state. The outcome in column 3 is defined as the maximum distance (in miles) between a worker's 2011 residence and their residential locations over the 2012–2019 period. For example, the outcome for a worker who lived in Welch, West Virginia between 2011 and 2014 before moving to Raleigh, North Carolina for one year in 2015 followed by a permanent move to Beckley, West Virginia in 2016 would be the straight-line distance between the latitude-longitude of his residence in Welch to the latitude-longitude of his residence in

Table B1: Exposure to coal shock and the evolution of earnings: Sensitivity to controls

	(1)	(2)	(3)	(4)	(5)
Panel A: Cumulative earnings					
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-2.038***	-1.912***	-1.775***	-1.681***	-1.597***
	(0.119)	(0.086)	(0.087)	(0.089)	(0.087)
Panel B: Cumulative employment					
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.396***	-0.344***	-0.297***	-0.317***	-0.370***
	(0.049)	(0.040)	(0.038)	(0.039)	(0.037)
Panel C: Earnings per year of employment					
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.227***	-0.215***	-0.203***	-0.189***	-0.174***
	(0.013)	(0.010)	(0.010)	(0.011)	(0.010)
Region FE		✓	✓	✓	✓
Demographic controls			✓	✓	✓
Employment controls				✓	✓
Earnings controls					✓
Observations	152,000	152,000	152,000	152,000	152,000

The outcome variables are defined over the 2012 to 2019 period. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. Demographic controls include age, an indicator for being non-Hispanic white, and an indicator for being male. Employment controls include tenure at 2011 firm between 2007 and 2011, the change in average annual wages between 2007 and 2011, and 8 bins of 2011 establishment size. Earnings controls include the log of average annual wages between 2007 and 2011 and the interaction of average wages with the worker's age. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** $p<0.001$, ** $p<0.01$, * $p<0.05$

Raleigh.

In column 1, we estimate that greater exposure to the coal shock is not associated with the number of years in which a worker lives in his or her 2011 CZ between 2012 and 2019. The point estimate in column 2 indicates that exposed coal workers spend a modest amount of additional time in their 2011 state. The coefficient suggests that they spend about 0.18 additional years, or over two months, in the same state over the 2012–2019

Table B2: Exposure to coal shock and geographic mobility, 2012-2019

	(1) # of years in 2011 CZ	(2) # of years in 2011 state	(3) Farthest distance from 2011 residence (miles)
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	0.069	0.183***	-42.680***
	(0.036)	(0.026)	(4.723)
Outcome mean (SD)	7.02 (2.20)	7.52 (1.56)	89.38 (309.50)
Controls	✓	✓	✓
Region FE	✓	✓	✓
Observations	152,000	152,000	152,000

The outcome variables are defined over the 2012 to 2019 period. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** p<0.001, ** p<0.01, * p<0.05

period. Exposed coal workers appear to move to less distant locations than observationally similar workers. They travel about 43 miles less to their farthest residence from their residence in 2011. This evidence offers a somewhat nuanced portrait of geographic mobility. Exposed coal workers do not appear to spend more or less time in their immediate labor market during the years of coal's decline, but they do spend more time in their 2011 state of residence and move within more proximate locations than observationally similar workers.

B.3 Spatial spillovers

Labor supply is responsive not only to the economic conditions in a local labor market but also to those conditions in possible alternative destinations (Borusyak et al., 2022). Relatedly, local labor demand depends on local economic conditions as well as the economic conditions in proximate labor markets (Adão et al., 2019; Redding, 2022). Our primary empirical strategy detailed in section 4.1 defines "exposure" to the coal shock based on an individual worker's tenure in the coal mining industry. This strategy exploits the fact that individuals with a relatively greater attachment to the industry will be relatively more exposed to the national collapse in demand for coal. While tenure in the industry is certainly a key factor influencing whether a worker will be affected by this macroeconomic coal shock, geographic location will also play a large role. Tenured coal workers living in regions with relatively large concentrations of coal mining employment may suffer from the individual consequences of the coal shock, as well as the broader consequences the shock has on the local community.

To address these spatial spillovers, we add to equation 2 a control variable that reflects regional exposure to the coal shock. This variable for worker i in CZ j, ϕ_{ij}, is a gravity-weighted measure of the CZ's proximity to other regions' coal shock exposure:

$$\phi_{ij} = \sum_{c \in j} \gamma_c \left(\sum_{c'} \omega_{cc'} \times Coal_{c'}^{2005} \right) \tag{3}$$

where $Coal_{c'}^{2005}$ is the coal mining employment share of the population in county $c' \neq c$ in 2005. This variable serves as a county's exposure to the subsequent "coal shock.".[1] The intuition is that communities in which coal was relatively more concentrated preceding the large-scale decline in demand for coal were relatively more exposed to this macroeconomic coal shock.[2] We weight this exposure variable by $\omega_{cc'}$, which reflects the spatial proximity, or gravity-weighted distance, between county c and $c' \neq c$:

$$\omega_{cc'} \equiv \frac{N_{c'} D_{cc'}^{-\delta}}{\sum_k N_k D_{ck}^{-\delta}} \tag{4}$$

where $N_{c'}$ is the 2005 population of county c', $D_{cc'}$ is the distance (in miles) between county

[1] The coal mining employment share of the population is highly correlated over time. Using instead the 2011 coal share to identify exposure to the shock, for example, yields similar results.

[2] This exposure variable can be thought of as the "share" in a single industry Bartik shift-share instrument, where the "shift" is the macroeconomic shift in demand for coal, which is common to all counties (Bartik, 1991; Goldsmith-Pinkham et al., 2020; Krause, 2023).

c and c', and δ is the trade-cost elasticity which, following Autor et al. (2021), we set equal to 5. The weight γ_c is the population of county c, and thus we take a population-weighted average of $\sum_{c'} \omega_{cc'} \times Coal_{c'}^{2005}$ for all counties c in CZ j to generate ϕ_{ij}. The variable ϕ_{ij} thus reflects a weighted sum of all other CZ's exposure to the coal shock. We define this variable for worker i based on the CZ j in which he or she lived in 2011.

Table B3: Exposure to coal shock and the evolution of earnings, controlling for spatial proximity to coal shocks

	(1) Cumulative earnings	(2) # of years w/ earnings >0	(3) Earnings per year employed
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.021***	-0.212***	-0.112***
	(0.083)	(0.034)	(0.010)
Outcome mean (SD)	8.05 (3.71)	7.45 (1.43)	1.06 (0.43)
Controls	✓	✓	✓
Spatial proximity control (ϕ_{ij})	✓	✓	✓
Region FE	✓	✓	✓
Observations	152,000	152,000	152,000

The outcome variables are defined over the 2012 to 2019 period. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2, as well as the control for spatial linkages defined in equation 3. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** p<0.001, ** p<0.01, * p<0.05

Table B3 reports the coefficient estimates β_1 from equation 2 with the inclusion of this control for regional exposure to the coal shock. The point estimates can be compared to the central estimates presented in Table 2. The magnitude of the coefficients on cumulative earnings and employment is between 36 and 43 percent smaller than the central estimates when controlling for spatial proximity to the coal shock. This indicates that controlling for the indirect effects of shocks in proximate labor markets indeed dampens the direct effects of the individual-level shock exposure (Adão et al., 2019).

While we have omitted the results from this paper, controlling for spatial linkages does not alter the conclusions drawn from the decomposition exercises reported in Tables 3 through B9. Though the coefficients are again smaller in magnitude, the conclusions drawn from this specification are similar to those drawn from the primary analysis. Our primary specification can be thought of as revealing the total effect of being a "tenured" coal worker, relatively more exposed to the coal shock, on future earnings and employment. Controlling for the indirect effects of spatial linkages somewhat attenuates the overall effect of individual-level exposure, confirming that the economic conditions in related labor markets also influence an individual's earnings and employment trajectory.

B.4 Alternatives definition of coal shock exposure

Our primary measure of individual-level "exposure" to the coal shock, $\mathbb{1}[Coal_{i,2007\text{-}11}]$, is a dummy variable characterizing whether or not the worker worked for coal in all five years between 2007 and 2011. This is a relatively conservative measure of exposure, as some workers with relatively lesser tenure in the coal industry are still exposed to the adverse labor market consequences of declining demand for coal. This would have the effect of biasing our primary estimates toward zero. In two alternative specifications, we define exposure based on the number of years in which the coal mining industry was the worker's primary source of earnings between 2007 and 2011. In the first specification, we define exposure as a continuous variable reflecting the number of years worked in a coal mining establishment. In the second, we use a binned treatment variable.

B.4.1 Continuous measure of coal exposure

Using the sample sample of workers who worked full-time in all years from 2007 through 2011, we estimate an analogous version of equation 2:

$$E_{i\tau} = \beta_0 + \beta_1 \left(YC_{i,2007\text{-}11}\right) + X'_{i,0}\beta_2 + \delta_r + \varepsilon_{i\tau} \tag{5}$$

where $YC_{i,2007\text{-}11}$ reflects the number of years between 2007 and 2011 that worker i's primary earnings came from the coal industry. Now, β_1 represents the effect of an additional year of attachment to the coal industry in the years preceding the coal shock. We include the same set of worker-level controls and again limit our analysis to workers who worked full-time in all five of these pre-shock years. The results from this exercise are reported

Table B4: Exposure to coal shock and the evolution of earnings using a continuous measure of exposure

	(1) Cumulative earnings	(2) # of years w/ earnings >0	(3) Earnings per year employed
# Years in coal, 2007–2011	-0.434***	-0.095***	-0.048***
	(0.027)	(0.009)	(0.003)
Outcome mean (SD)	8.05 (3.71)	7.45 (1.43)	1.06 (0.43)
Controls	✓	✓	✓
Region FE	✓	✓	✓
Observations	152,000	152,000	152,000

The outcome variables are defined over the 2012 to 2019 period. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a continuous variable indicating the number of years in which the worker's primary earnings were drawn from the coal industry between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** p<0.001, ** p<0.01, * p<0.05

in Table B4. The point estimates reveal that an additional year of working full-time for the industry in the years preceding the shock yields a decline in cumulative earnings between 2012 and 2019 of nearly one-half of the average annual earnings earned during the 2007 to 2011 period. This additional year of attachment yields a decline in the number of years worked between 2012 and 2019 of about 10 percent of a year, or about 5 weeks, and a decline in earnings per year employed of 4.8 percent per year relative to the 2007–2011 annual wage. The qualitative conclusions are largely similar to those drawn from the primary analysis. Exposure to coal's recent decline, defined based on a worker's tenure in the coal industry in the pre-shock period, yields relatively large earnings and employment losses between 2012 and 2019 when the coal shock was in full force.

B.4.2 Binned treatment variable

The results in Section B.4.1 suggest that additional years of "exposure" to the coal shock — in terms of tenure in the coal industry — are associated with aggregate earnings and employment losses. However, if the effect of exposure is nonlinear, the average treatment captured in the estimates presented above will not reflect this nonlinearity. In Table B5, we present the estimates from transforming the continuous measure of coal exposure into a binned treatment variable, where we bin the number of years in which the worker's primary earnings were drawn from the coal industry between 2007 and 2011 into three groups: zero, between 1 and 3 years, and between 4 and 5 years.[3] The remainder of the specification is exactly as before.

The coefficient estimates in Table B5 confirm that workers with greater exposure to the coal shock, in terms of tenure in the industry between 2007 and 2011, experience larger cumulative earnings and employment losses than workers with no or partial exposure to the shock. Individuals who worked in the coal industry for 4-5 years between 2007 and 2011 lost about 2 years' worth of earnings between 2012 and 2019 in terms of their 2007–2011 annual earnings, while those who worked for 1-3 years lost only 0.7 year's worth of earnings. Both of these estimates are relative to workers who worked zero years in the coal industry between 2007 and 2011. The effect on the extensive margin — the number of years worked between 2012 and 2019 — is nearly three times as large for the most exposed workers relative to partially exposed workers. The effect on the intensive margin — earnings per year employed — is nearly three times as large for the most exposed workers. Scaling the coefficient estimates in columns 1-3 from Table B4 by the number of

[3]There are several possible cutoffs or methods to bin the continuous exposure variable, including allowing for one bin per year of exposure. The conclusions are insensitive to this choice.

Table B5: Exposure to coal shock and the evolution of earnings using a binned treatment variable

	(1) Cumulative earnings	(2) # of years w/ earnings >0	(3) Earnings per year employed
1-3 years in coal, 2007–11	-0.713***	-0.163***	-0.077***
	(0.098)	(0.027)	(0.011)
4-5 years in coal, 2007–11	-2.049***	-0.454***	-0.225***
	(0.133)	(0.043)	(0.015)
Outcome mean (SD)	8.05 (3.71)	7.45 (1.43)	1.06 (0.43)
Controls	✓	✓	✓
Region FE	✓	✓	✓
Observations	152,000	152,000	152,000

The outcome variables are defined over the 2012 to 2019 period. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a binned variable indicating the number of years in which the worker's primary earnings were drawn from the coal industry between 2007 and 2011 (zero, between 1 and 3 years, and between 4 and 5 years). All regressions include the full set of worker-level controls from equation 2. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** $p<0.001$, ** $p<0.01$, * $p<0.05$

years in each bin reveals that these estimates are roughly consistent with a relatively linear effect of exposure on outcomes.[4] Comparing the magnitude of the coefficients in Table B5 to those in Table 2 confirms that the inclusion of "partially exposed" coal workers in the control group in the main analysis serves to attenuate the main estimates. For this reason, we consider our central estimates a lower bound of the effect of exposure on aggregate earnings and employment losses.

[4]In separate analyses, we also consider a categorical measure of exposure, which effectively produces a bin for each possible extent of exposure (0, 1, 2, 3, 4, and 5 years). This exercise confirms that the earnings and employment effects are roughly linear in the number of years of exposure up until 4 years, after which they level off somewhat.

B.4.3 Within-coal analysis

The estimates in Appendix sections B.4.1 and B.4.2 indicate that individuals with "partial" exposure to coal's decline also suffered earnings and employment losses during the 2012–2019 period. Thanks to the high spatial concentration of coal mining activity, if there were some, other (non-coal-related) shock or change over time that differentially affected coal communities, both partially exposed coal workers and the most exposed coal workers (i.e., the "treated" coal workers) would be subject to its consequences. If another geographically concentrated change adversely influenced coal communities, we might misattribute its consequences to the decline in coal. In this section, we explore how the most exposed group of coal workers fared relative to these other, less exposed coal workers. In Table B6, we limit the analysis to individuals who worked full-time in all years 2007–2011 (as before) and whose primary employer was a coal establishment in at least one of these years. Limiting the analysis to only coal workers has the advantage of absorbing other spurious economic conditions or shocks that differentially influence coal communities. All other details about the specification are exactly as in our primary analysis. "Treated" coal workers are those who worked in coal for all five years during the pre-shock period.

The conclusions drawn from Table B6 are broadly similar to those drawn from the primary specification. Relative to other coal workers with less exposure to the shock, the most exposed coal workers experienced a decline in earnings amounting to an entire year's worth of earnings over the 2012–2019 period, with both extensive and intensive margins responses contributing. The slight attenuation of the coefficients is consistent with the finding that these partially exposed coal workers are indeed treated to some extent by the decline in coal.

Table B6: Exposure to coal shock and the evolution of earnings, sample of only coal workers

	(1) Cumulative earnings	(2) # of years w/ earnings >0	(3) Earnings per year employed
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.083***	-0.243***	-0.118***
	(0.066)	(0.037)	(0.007)
Outcome mean (SD)	7.25 (3.40)	7.26 (1.64)	0.97 (0.38)
Controls	✓	✓	✓
Region FE	✓	✓	✓
Observations	61,500	61,500	61,500

The outcome variables are defined over the 2012 to 2019 period. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. The sample is limited to individuals who worked at least one year in coal between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** $p<0.001$, ** $p<0.01$, * $p<0.05$

B.4.4 Control for industry tenure

Our central specification defines a worker's exposure to the coal shock based on his or her tenure in the coal industry during the pre-shock period. One might be concerned that workers with five years of consecutive tenure in a single industry might have different employment or earnings potential than workers who switched industries over the 2007–2011 period. The specification used to produce the estimates in Table B7 is identical to that outlined by equation 2, with one additional control variable: the binned number of years in which the worker worked for his or her 2011 (2-digit) industry over the 2007–2011 period. The point estimates are quantitatively similar to those in Table 2. Compared to observationally similar workers with substantial tenure in their respective industries during the 2007–2011 period, exposed coal workers suffered large cumulative earnings losses over the 2012–2019 period, driven both by extensive and intensive margin responses.

Table B7: Exposure to coal shock and the evolution of earnings, controlling for industry tenure

	(1) Cumulative earnings	(2) # of years w/ earnings >0	(3) Earnings per year employed
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.547***	-0.401***	-0.165***
	(0.091)	(0.040)	(0.010)
Outcome mean (SD)	8.05 (3.71)	7.45 (1.43)	1.06 (0.43)
Controls	✓	✓	✓
Binned tenure in 2011 industry	✓	✓	✓
Region FE	✓	✓	✓
Observations	152,000	152,000	152,000

The outcome variables are defined over the 2012 to 2019 period. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2, as well as a control for the (binned) number of years in which the worker worked for his or her 2011 industry over the 2007–2011 period, where industry is based on 2-digit NAICS code. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** p<0.001, ** p<0.01, * p<0.05

B.5 Does the Type of Outside Industry Matter?

Do other industries offer differential opportunities for coal workers to adjust? Coal mining has historically offered exceptionally high wages for individuals with relatively low levels of educational attainment. Card et al. (2023) notes that the coal industry offers a uniquely high wage premium. In this section, we explore whether entering other "high-wage" industries attenuates the aggregate earnings losses documented above.

In Table B8, we decompose the total worker-level effect of coal shock exposure (column 1) into earnings and employment changes by geographic location, industry, and the industry wage level. Columns 2, 3, and 5 correspond to columns 1, 2, and 4 from Table 4. We define "high-wage" industries as those that pay the same or more than the 2-digit NAICS code containing coal mining ("Mining, Quarrying, and Oil and Gas Extraction"), and "low-wage" industries as those that pay less. We calculate industry wages at the 2-digit NAICS code by taking the mean earnings for workers in our sample who worked full-time in 2005.[5] Based on this strategy, four industries were high-wage industries compared to the mining industry (NAICS code 21): utilities (22), information (51), finance and insurance (52), professional, scientific, and technical services (54), and management (55).[6]

Table B8 shows that exposed coal workers' aggregate losses are not attenuated by earnings and employment observed in other high-wage industries. While losses are apparent in both high- and low-wage industries across labor markets, cumulative losses are driven by years observed in higher-wage industries. Exposed coal workers lose about 0.84 years' worth of earnings in other high-wage industries within their local labor market (column 3) and about 0.22 years' worth of earnings in other high-wage industries in different labor markets (column 6) relative to workers with less or no exposure. These earnings losses are large in relative terms, implying a reduction of over 100 percent of the sample means.

We observe that it is rare for coal workers to transition into these high-wage industries. Only one of these industries appears in Figure 4, which showed that management served as the modal non-coal industry for about 4 percent of coal workers in the age-restricted sample. Consistent with this, Panel B of Table B8 implies that exposed coal workers spend fewer years employed in other high-wage industries compared to control workers. The point estimates in column 3 (-0.656) and column 6 (-0.158) again represent about a 100 percent decline over the associated sample means, suggesting that exposed coal workers are extremely unlikely to be employed in these other high-wage industries

[5] Again, we define a worker as "full-time" if their earnings are greater than what they would earn by working 1,600 hours (about 30 hours per week) at the federal minimum wage. In 2005, the minimum wage was $5.15, so this implies workers who reported earnings of at least $8,240. We code "missing" NAICS codes (typically agriculture or government) as a single industry.

[6] We do not condition on education in determining these high-wage industries. Coal miners have relatively low levels of educational attainment compared to workers employed in these high-wage industries. The only industry that paid higher wages than the mining sector to individuals with less than a college degree in 2005 was utilities. Conducting this analysis with utilities as the only high-wage, non-mining sector yields similar conclusions to that in B8.

Table B8: Exposure to coal shock and the evolution of earnings by geographic location and industry wage

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	All		**Same CZ**			**Different CZ**	
Same industry		Yes	No	No	Yes	No	No
High-wage industry		-	Yes	No	-	Yes	No
Panel A: Cumulative earnings							
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.597***	0.070	-0.844***	-0.507***	0.020	-0.218***	-0.118***
	(0.087)	(0.104)	(0.064)	(0.062)	(0.026)	(0.015)	(0.014)
Outcome mean (SD)	8.05 (3.71)	4.99 (3.89)	0.83 (2.35)	1.23 (2.48)	0.51 (1.87)	0.20 (1.23)	0.30 (1.32)
Panel B: Cumulative employment							
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.370***	0.637***	-0.656***	-0.244***	0.101***	-0.158***	-0.051***
	(0.037)	(0.113)	(0.055)	(0.066)	(0.023)	(0.011)	(0.013)
Outcome mean (SD)	7.45 (1.43)	4.57 (3.03)	0.68 (1.63)	1.31 (2.14)	0.43 (1.39)	0.15 (0.76)	0.30 (1.10)
Panel C: Earnings per year of employment							
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.174***	-0.134***	-0.238***	-0.285***	-0.162***	-0.312***	-0.269***
	(0.010)	(0.010)	(0.047)	(0.013)	(0.012)	(0.028)	(0.013)
Outcome mean (SD)	1.06 (0.43)	1.06 (0.36)	1.14 (0.58)	0.89 (0.57)	1.11 (0.58)	1.26 (0.77)	0.92 (0.67)
Controls	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓	✓	✓	✓	✓	✓
Obs. (Panels A and B)	152,000	152,000	152,000	152,000	152,000	152,000	152,000
Obs. (Panel C)	152,000	132,000	34,000	58,000	19,500	8,000	15,500

The outcome variables are defined over the 2012 to 2019 period. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Column 1 shows aggregate effect on cumulative earnings and employment. Columns 2–7 decompose these effects into employment and earnings obtained in the 2011 CZ of residence versus other CZs, within the 2011 industry of employment versus outside of this industry, and within a high-wage industry versus outside of a high-wage industry. High-wage industries include utilities, information, finance and insurance, professional, scientific, and technical services, and management. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** p<0.001, ** p<0.01, * p<0.05

compared to workers with less or no exposure. This is consistent with the highly specialized nature of the skills demanded by the coal industry, which may not translate well to other high-wage industries. At the same time, coal mining is concentrated in relatively remote places where job opportunities in other high-wage industries are often scarce. Still, the estimates in Table B8 reveal that exposed coal workers who do spend time employed in other high-wage industries in other labor markets experience relatively large declines in earnings per year employed.

B.6 The role of spillovers and industrial sector

In this section, we consider potential heterogeneity in earnings and employment trajectories based on the extent to which an industry depends on local demand. This exercise is motivated by the observation that local industries may be differentially exposed to the spillover effects of local employment declines in the coal industry. Non-tradable industries that rely on local demand may be more vulnerable to the negative spillovers associated with declining local labor market opportunities in other industries (Moretti, 2011; Aragón and Rud, 2013; Mian and Sufi, 2014). Given that exposure to the coal shock does not appear to promote substantial geographic mobility, exposed workers' earnings and employment trajectories in non-mining industries may be dictated to some degree by these local spillovers. We define industries as tradable, non-tradable, construction, or other following the categorization in Mian and Sufi (2014), who define retail- and restaurant-related industries as non-tradable, and industries that show up in global trade data as tradable. Specifically, tradable industries are classified as 4-digit NAICS industries for which imports plus exports equal at least $10,000 per worker or $500M total. Non-tradable industries include the retail sector and restaurants, and construction includes 4-digit industries related to construction, real estate, or land development. Other includes all other 4-digit industries.[7]

Table B9 reports this decomposition. Noting that coal mining is classified as a tradable industry, the point estimates in column 2 demonstrate that cumulative earnings and employment losses for exposed coal workers are attenuated by employment within the tradable industry category.[8] The largest contribution to reductions in cumulative earnings

[7]Other includes many service-oriented industries, including accommodations, education, health care and social assistance, and other services. The precise definitions of each category are provided in the supplemental materials in Mian and Sufi (2014).

[8]Distinguishing coal from other tradable industries indicates that the positive coefficient in column 2 is almost entirely driven by years that exposed coal workers spend in coal mining (rather than other tradable

Table B9: Exposure to coal shock and the evolution of earnings geographic location and industrial sector

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All	**Same CZ**				**Different CZ**			
		Tradable	Non-trad.	Const.	Other	Tradable	Non-trad.	Const.	Other
Panel A: Cumulative earnings									
$\mathbf{1}[Coal_{i,2007\text{-}11}]$	-1.597***	2.234***	-0.160***	-0.484***	-2.871***	0.138***	-0.020***	-0.074***	-0.360***
	(0.087)	(0.206)	(0.048)	(0.037)	(0.154)	(0.032)	(0.005)	(0.010)	(0.021)
Outcome mean (SD)	8.05 (3.71)	2.53 (3.60)	0.30 (1.47)	0.56 (1.93)	3.66 (4.19)	0.36 (1.53)	0.04 (0.53)	0.09 (0.72)	0.51 (1.97)
Panel B: Cumulative employment									
$\mathbf{1}[Coal_{i,2007\text{-}11}]$	-0.370***	2.721***	-0.145**	-0.407***	-2.432***	0.230***	-0.016***	-0.054***	-0.267***
	(0.037)	(0.164)	(0.045)	(0.032)	(0.150)	(0.028)	(0.004)	(0.009)	(0.016)
Outcome mean (SD)	7.45 (1.43)	2.30 (2.99)	0.31 (1.33)	0.54 (1.63)	3.42 (3.31)	0.31 (1.17)	0.04 (0.40)	0.09 (0.58)	0.45 (1.41)
Panel C: Earnings per year of employment									
$\mathbf{1}[Coal_{i,2007\text{-}11}]$	-0.174***	-0.133***	-0.480***	-0.287***	-0.333***	-0.193***	-0.405***	-0.286***	-0.345***
	(0.010)	(0.007)	(0.032)	(0.014)	(0.025)	(0.017)	(0.046)	(0.024)	(0.016)
Outcome mean (SD)	1.06 (0.43)	1.08 (0.42)	0.86 (0.47)	0.95 (0.47)	1.02 (0.48)	1.13 (0.58)	0.79 (0.66)	0.96 (0.60)	1.05 (0.70)
Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓
Region FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
Obs. (Panels A and B)	152,000	152,000	152,000	152,000	152,000	152,000	152,000	152,000	152,000
Obs. (Panel C)	152,000	73,500	11,000	22,000	101,000	14,500	2,300	5,100	20,000

The outcome variables are defined over the 2012 to 2019 period. Cumulative earnings and earnings per year employed are normalized to average annual wages between 2007 and 2011. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Column 1 shows aggregate effect on cumulative earnings and employment. Columns 2–9 decompose these effects into employment and earnings obtained in the 2011 CZ of residence versus other CZs, and within versus outside of different industrial sectors, defined in the text. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** p<0.001, ** p<0.01, * p<0.05

and employment comes from employment in the "other" category. The point estimate in column 5 of Panel B indicates that exposed coal workers spend 2.4 fewer years employed in "other" industries within their initial CZ than observationally similar workers.

Panel C of Table B9 provides additional insight into how earnings may be affected by employment opportunities in these different sectors. We estimate that reductions in earnings during years of employment are substantially larger when workers are engaged in non-tradable, construction, and other industries than when they are engaged in tradable industries (which, again, includes coal mining). Comparing the point estimates in

industries).

columns 2 and 3 of Panel C indicates that the reduction in earnings per year employed is about three times as large for years employed in "non-tradable" industries compared to years employed in "tradable" industries. This could be because non-tradable industries more heavily dependent on local demand are adversely affected by the spillover effects of the decline in coal, or because exposed coal workers are relatively less productive in these industrial sectors than control workers. Of note, we do not see meaningful differences in earnings per year of employment when comparing within industrial category across labor markets, indicating that indirect reductions in local demand may not be a substantial driver of the intensive margin of earnings losses relative to the direct effect on workers. Still, adverse local spillovers could contribute to the extensive margin by reducing employment opportunities within an affected labor market.

B.7 Retirement withdrawals and pension contributions

Exposed coal workers may supplement lost earned income and reduced employment opportunities with greater reliance on retirement resources. Workers may choose to retire early during contractions in the sector or following a specific displacement event, which may contribute to lower living standards later in life (Gruber and Orszag, 2003; Card et al., 2014). We observe workers' retirement income receipt from form 1099-R, which offers the total gross retirement withdrawals or pensions a worker receives in a year. We differentiate between IRA/401k withdrawals and pension contributions. We consider the effect of exposure to the coal shock on these withdrawals and contributions over the 2012–2019 period using the strategy outlined in Section 4.1. We consider both the number of years over the 2012–2019 period that a worker receives a 1099-R, indicating any retirement/pension drawdown, as well as the cumulative gross drawdown over this period, normalized to average annual 2007–2011 earnings.

Table B10 reports these results. In Panel A, the outcome is the cumulative num-

Table B10: Exposure to coal shock and retirement receipt, 2012-2019

	(1)	(2)	(3)	(4)	(5)	(6)
	Any retirement		Defined contribution		Defined benefit (pension)	
Panel A: Cumulative number of years of receipt						
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	0.430***	0.347***	0.119**	0.079*	0.410***	0.318***
	0.060	0.071	0.038	0.040	0.060	0.075
Outcome mean (SD)	1.57 (2.01)	1.30 (1.70)	0.50 (1.20)	0.40 (1.04)	1.22 (1.83)	0.98 (1.48)
Panel B: Cumulative receipt, normalized by 2007–11 earnings						
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	0.135***	0.139***	0.063***	0.049***	0.072***	0.090***
	0.019	0.017	0.013	0.013	0.015	0.015
Outcome mean (SD)	0.46 (0.94)	0.34 (0.69)	0.12 (0.44)	0.09 (0.34)	0.34 (0.79)	0.25 (0.59)
Controls	✓	✓	✓	✓	✓	✓
Region FE	✓	✓	✓	✓	✓	✓
Sample	all	born 1960-	all	born 1960-	all	born 1960-
Observations	152,000	123,000	152,000	123,000	152,000	123,000

The outcome variables are defined over the 2012 to 2019 period. In panel A, the outcome variable is defined as the cumulative number of years of receipt of the retirement type indicated over the 2012–2019 period. In panel B, the outcome is defined as the cumulative receipt from the retirement type indicated over the 2012–2019 period, normalized by average annual earnings between 2007 and 2011. Columns 1 and 2 include any distributions from a retirement account. Columns 3 and 4 consider distributions from any defined contribution account. Columns 5 and 6 consider pension annuities from a defined benefit plan. In even-numbered columns, the sample is restricted to workers born on or after 1960. The primary independent variable is a dummy variable indicating whether or not the worker's primary earnings were drawn from the coal industry in all five years between 2007 and 2011. All regressions include the full set of worker-level controls from equation 2. Robust standard errors in parentheses are clustered on the worker's firm in 2011. Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register.
*** $p<0.001$, ** $p<0.01$, * $p<0.05$

ber of years between 2012 and 2019 that a worker receives the retirement resource indicated. In Panel B, the outcome is the cumulative receipt, normalized by pre-shock earnings. Columns 1 and 2 include both IRA/401k withdrawals and pension contributions. Columns 3 and 4 consider only IRA/401k withdrawals, and columns 5 and 6 consider only defined benefit (pension) contributions. The sample in even-numbered columns is restricted to workers born in 1960 or later, such that they are no more than 59 in 2019, the final year of analysis.

The point estimates in column 1 indicate that exposed coal workers spend an additional 0.43 years receiving any retirement income — an increase of over one-quarter of the sample mean. Total retirement receipts over the 2012–2019 period amount to 0.135 years' worth of pre-shock earnings. These results are relatively stable when considering the slightly younger cohort in column 2. The greater reliance on retirement income among exposed coal workers is due to both IRA/401k withdrawals and pension contributions. Exposure to the coal shock induces workers to spend 0.12 additional years receiving 1099-R income from an IRA/401k account and an additional 0.41 years receiving 1099-R income from a defined pension plan. This results in an additional 0.06 years' worth of earnings received from an IRA/401k account and an additional 0.09 years' worth of earnings from pensions. The effect of coal shock exposure on cumulative pension receipt appears driven by the slightly younger cohort of workers. These findings are consistent with the results related to SSA-1099 receipt. Exposed coal workers recoup some portion of lost earnings with alternative sources of income, though the combination of increased retirement and increased SSA income only amounts to a fraction of cumulative earnings losses over the 2012–2019 period.

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