TRANSITIONAL COSTS AND THE DECLINE OF COAL: WORKER-LEVEL EVIDENCE*

Jonathan Colmer
University of Virginia

Eleanor Krause
Harvard University

Eva Lyubich
U.S. Census Bureau

John Voorheis
U.S. Census Bureau

Abstract

How has the transition away from coal affected coal workers? Using longitudinal administrative records containing the population of W-2 workers in the United States between 2005 and 2021, we evaluate the transitional consequences of the decline of coal. First, we document the characteristics, earnings, and employment trajectories of coal workers. Second, we quantify worker-level responses to the decline of coal. We find that, on average, coal workers most exposed to the decline lost almost a year and a half's worth of cumulative earnings, spent 0.32 fewer years employed, and experienced a 16 percent reduction in earnings per year over the 2012–2019 period compared to observationally similar workers with less exposure to the decline. Losses are driven by years in which workers do not work in mining and extraction activities but remain in their local labor markets. We find little evidence that coal workers are less geographically mobile than other workers; however, relocating to other labor markets does little to mitigate losses.

*This Version: February 2024. Correspondence: eleanorkrause@fas.harvard.edu. Affiliations: Colmer—Department of Economics, University of Virginia, USA; Krause—Harvard Kennedy School, USA; Lyubich—U.S. Census Bureau, USA; Voorheis—U.S. Census Bureau, USA. All errors and omissions remain our own. Any opinions and conclusions expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Census Bureau. The Census Bureau's Disclosure Review Board and Disclosure Avoidance Officers have reviewed this data product for unauthorized disclosure of confidential information and have approved the disclosure avoidance practices applied to this release, authorization numbers CBDRB-FY23-CES019-022, CBDRB-FY24-CES019-004 and CBDRB-FY24-CES019-005.

1 Introduction

How much is the energy transition going to disrupt the lives of American workers? The recent shift away from coal as the dominant source of electricity has resulted in lower levels of employment and earnings, increased rates of transfer receipt, and declining local revenues in coal-dependent communities (Morris et al., 2019; Hanson, 2022; Blonz et al., 2023; Krause, 2023), but these community-level responses are consistent with many possible dimensions of worker-level adjustment. If exposed workers are able to adjust quickly to new jobs in different industries or labor markets without significant earnings losses, the welfare consequences of the energy transition may be minimal. If, however, workers incur large transitional costs — because they lose firm- or industry-specific skills, or because migration or search costs are high — the welfare consequences may be substantial. Distinguishing the degree to which workers adjust along various margins is essential to understanding the transitional costs associated with the decline of coal, and for informing efforts to minimize the distributional labor force consequences associated with the broader shift away from fossil fuels.

In this paper, we present new evidence on precisely how coal workers have responded to declining coal demand, examining the degree and speed at which different margins of adjustment occur. Our approach leverages linked employer-employee data from the U.S. Census Bureau and Internal Revenue Service (IRS) on the universe of individuals who earned wages from establishments in the coal mining industry between 2005 and 2021. We combine these data with the 2005–2021 employment histories of a large random sample of individuals working in other industries, who serve as a comparison group.

Using these data, we first present new facts on *who* works in coal extraction related industries, offering a comprehensive portrait of workers' demographic characteristics, their earnings and income profiles, their locations of residence, and we describe how the characteristics of coal workers have evolved over time as some workers separate from the industry. We show that coal workers are more likely to be male and non-Hispanic white than non-coal workers and are much less likely to have a college degree. Despite educational differences, coal-worker earnings are substantially higher than non-coal workers. We further show that the number of coal workers declined substantially over our sample period. Eighty percent of coal workers separated from coal at some point during this period. Non-employment was the modal activity for more than 30% of these workers during non-coal years, indicating that the transitional costs associated with the decline of coal may be substantial.

Second, we quantify the consequences of the decline in coal on both intensive and extensive margins of adjustment, examining the impact on workers' cumulative earnings and employment, as well as the roles that sectoral and geographic mobility play in attenuating these impacts. Our empirical approach exploits differential worker-level exposure to the most recent "coal shock," which began in earnest following the industry's contemporary peak in 2011. After years of relatively stable demand for the resource, U.S. coal mining employment declined by over 50 percent between 2011 and 2021, as national demand for coal waned in favor of less expensive natural gas made widely accessible thanks to major advances in hydraulic fracturing technology (Kolstad, 2017; Linn and McCormack, 2019; Coglianese et al., 2020; Davis et al., 2022).[1] Our analysis leverages the fact that workers with greater "attachment" to the coal mining industry in the years preceding the recent coal shock are relatively more exposed to this macroeconomic shift in demand for coal, where attachment is defined based on a worker's employment history in the industry. The richness of our data enables us to compare observationally similar workers who differ only in the number of years in which they report earnings from coal mining establishments in the pre-shock period.

We find that, between 2012 and 2019, workers who were most exposed to the coal shock suffered large earnings losses and spent more months in non-employment than

[1] Demand for coal has fluctuated substantially over the past century due to macroeconomic conditions, improvements in mining technology, changes in the supply of competing commodities, and other factors. After declining by nearly 100,000 workers between the early 1980s and 2000 (a decline of about 57 percent), the industry added about 15,000 jobs in the first decade of the 21st century (Humphries, 2017). Unlike many other tradable industries, coal mining experienced a small uptick in employment during the Great Recession, which just preceded this most recent coal shock.

observationally similar workers who did not work in coal or worked in coal for fewer years in the pre-shock period. On average, exposed coal workers — who worked full-time for the coal mining industry in the years leading up to the contemporary coal shock — experienced a decline in cumulative earnings amounting to 1.43 times their 2007–2011 average annual earnings over the 2012–2019 period. Adjustments on both the extensive and intensive margin played a role in these earnings declines, as exposed coal workers worked about one-third of a year less than observationally similar workers, and suffered earnings losses in the years in which they *were* employed on the order of 19 percent per year relative to their 2007–2011 annual earnings.

We find substantial heterogeneity in the consequences of this decline in coal. Exploring various margins of adjustment, we estimate that aggregate earnings and employment losses are attenuated by years in which exposed coal workers are able to continue working in "Mining, Quarrying, and Oil and Gas Extraction" (NAICS code 21) activities, although they earn around 12 percent less per year in this industry between 2012 and 2019 relative to their 2007–2011 annual earnings. The attenuation effect is driven in equal parts by additional years of employment at their 2011 firm (i.e., years in which they are not displaced), as well as years in which workers separate from their initial (2011) firm but remain employed in the mining industry. Thanks to the uniquely high wages offered by the coal industry, these additional years of employment in the industry help to buffer aggregate losses, despite declines in earnings per year employed in the industry. By contrast, exposed coal workers' earnings and employment losses over the 2012–2019 period are driven by years in which they work in different industries or are not employed. They work 1.7 fewer years outside of their initial (2011) industry (mining) than observationally similar workers over this 8-year period, which includes years spent in non-employment. The magnitude of this effect is large, reflecting a decline of over 70 percent of the average (2.45 years). During the years in which they are employed in different industries, exposed workers earn 30 percent less per year relative to their average 2007–2011 earnings in coal.

We do not find strong evidence that coal workers are much less geographically mobile than non-coal workers, however, relocating does not appear to attenuate aggregate losses. Exposed coal workers suffer earnings losses both inside and outside of their initial Commuting Zones (CZs), although aggregate earnings losses are driven by years in which workers remain inside of their initial CZs and outside of their initial industries. Compared to observationally similar workers, we estimate that exposed coal workers experience a decline in earnings equivalent to 1.9 times their 2007–2011 average annual earnings and work 1.4 fewer years in different industries (including non-employment) *inside* of their initial CZ. They experience a decline in earnings equivalent to one half of a year's worth of earnings and work one-third of a year less in different industries (including non-employment) *outside* of their initial CZ. The effect of exposure on the intensive margin of earnings per year of employment is roughly similar for years employed inside and outside of one's initial CZ, conditional on industry of employment. Finally, we estimate substantial increases in SSDI payments, suggesting that coal workers may recoup some losses, but through what is arguably a "second-best" transfer mechanism. In summary, aggregate losses are driven by workers who separate from the industry, and moving across industries and labor markets does not attenuate these losses. To the extent that the clean energy transition redirects employment opportunities toward non-mining sectors outside of the labor markets traditionally built on extractive industries, our findings suggest that the transitional costs for exposed workers may be particularly large.

We make several contributions. First, we contribute to the literature on the labor market consequences of energy transitions. Much of the work on energy transitions identifies the consequences of these shifts for *communities* traditionally dependent upon fossil fuels (Black et al., 2002, 2003, 2005; Jacobsen and Parker, 2016; Morris et al., 2019; Hanson, 2022; Krause, 2023). Together, these studies provide compelling evidence that adverse shifts in demand negatively impact affected communities, with consequences ranging from large declines in total employment and average wages to increased reliance on government transfers. However, the extent to which these aggregate losses simply reflect shifts in the population composition versus real losses incurred by local residents remains unclear. We provide systematic and comprehensive evidence on the margins of adjustment through which *individual* workers respond following the substantial and persistent reduction in demand for coal beginning after 2011. Because we have detailed residential and employment histories for all W-2 workers, our data allow us to decompose the aggregate consequences along important margins of adjustment. Overall, our findings show that adjustment margins such as reallocation to other industries and labor markets provide limited mitigation of transitional costs for workers most exposed to the decline in coal.

We also contribute to the broader literature on the transitional costs of labor demand shocks. This literature has documented that the earnings losses associated with job displacement in other settings can be substantial and persistent, and are exacerbated when the event occurs in a distressed labor market or during an economic downturn (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). Existing work has tended to focus 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), which are less regionally concentrated than coal. Autor et al. (2014) document that the industry-level effects of the "China shock" are not capturing geographic variation in worker's trade exposure. By contrast, geographic variation is important in this context – while coal employment makes up a small share of total employment, it accounts for a meaningful share of local employment in coal-rich regions. To the extent that negative labor demand shocks substantively reduce local demand, this may exacerbate the consequences for workers by reducing opportunities for workers to reallocate within their local labor market. In contexts where employment is regionally concentrated, the consequences of negative labor demand shocks are intensified for directly affected workers, who have fewer margins of adjustment to manage the consequences. Consistent with this, we find little evidence that reallocation across industries within the local labor market mitigates the transitional costs for affected workers.

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

Building on the data linkage infrastructure 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 nationally representative household surveys 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).[2]

We begin with the set of all individuals in the Environmental Impacts Frame (EIF) from 2005 to 2021. The EIF is a curated microdata infrastructure that constructs consistent residential histories for nearly the entire U.S. Population using several sources of administrative data available within the Census Bureau. We link the EIF to the universe of IRS Form W-2s in each year so that we can identify the set of workers ever employed at coal mining establishments based on the EIN on the worker's W-2 tax form, defining

[2] The number of employees and establishments in Figure 1 are both rounded following Census disclosure avoidance rules.

the worker's employer based on the W-2 form with the highest annual earnings. If an EIN-year pair includes multiple establishments, we link the worker to the establishment that is geographically closest to the worker.[3]

Our relevant set of individuals are then individuals whose W-2 earnings came from a coal mining establishment in at least one year over the 2005–2021 period. We construct a panel dataset for these individuals by combining the EIF and W-2s, so that we have the entire 2005–2021 employment histories of these workers (including years in which they do not work for coal establishments) as well as their residential histories over this period. To this employer-employee panel, we link information on firm characteristics[4] from the Longitudinal Business Database (LBD), including employment, revenue and industry.

We link this balanced panel to two additional datasets to attach demographic characteristics. We link all individuals in the panel to the Demographic spine of the EIF (Voorheis et al., 2023), which includes basic demographic information (age, race, ethnicity, and sex). Additionally, for a sub-set (about 20 percent) of individuals who ever responded to the American Community Survey (ACS), we link detailed demographic information from the survey, including education, occupation (at survey response), marital status, and family structure.

Between 2005 and 2021, around 218,000 individuals worked for coal mining establishments as their primary source of W-2 earnings in at least one year. Because we define a worker's place of employment by the NAICS code of his or her establishment, our definition of "coal mining" employment will include individuals engaged in support roles within the establishment as well as individuals directly employed as coal miners. We will 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. Over this 17-year period, the number of individuals working for coal mining establishments as their pri-

[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.

[4]In most cases, EINs are the same as the LBD firm concept, but some large firms own multiple employer entities that have separate EINs.

mary source of earnings peaked at over 99,000 in 2011, and then fell by over 50 percent over the next decade (Figure 1).[5] Other work has shown that the large-scale decline in demand for coal observed over this period was macroeconomic in nature, driven largely by the sudden introduction of inexpensive natural gas made available by hydraulic fracturing technology (Kolstad, 2017; Linn and McCormack, 2019; Coglianese et al., 2020; Davis et al., 2022).[6] We refer to the period of declining coal demand following its contemporary peak in 2011 as the recent "coal shock."[7] While we provide summary statistics on coal workers over the entire 2005–2021 period, we conclude most quasi-experimental analyses in 2019 in order to avoid the potentially confounding effects of the Covid-19 pandemic and the associated economic crisis.

We offer descriptive details on this universe of coal workers as well as a restricted sample of 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 (around 142,000 workers), and at most 64 by 2019 (the conclusion of our quasi-experimental analysis period).[8] For our quasi-experimental analyses, we restrict to workers born between 1955 and 1985 who worked full-time in all five years preceding the recent coal shock (2007–2011), as detailed in Section 4. For these analyses, we add to this coal worker panel the 2005–2021 histories of a random sub-sample of individuals who responded to the 2010 ACS – a large, nationally representative sample. We construct these individuals' employment and earnings histories identically as the coal worker panel. The sub-sample is constructed by taking a random 10-percent sample of these ACS respondents who were born between 1955 and

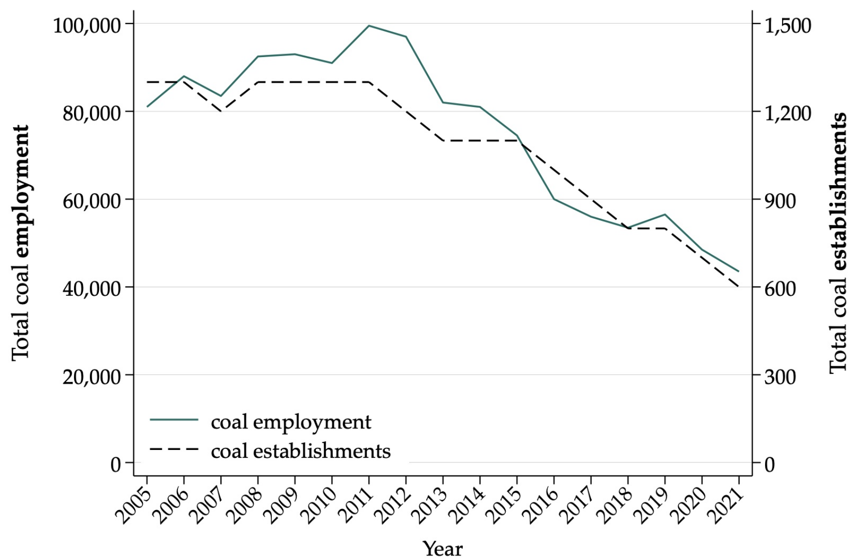
[5]The annual number of coal workers in our data set differs slightly from the number estimated from the CBP data or other official government statistics. Appendix Figure A1 compares the total number of coal miners in our dataset to that derived from the CBP. The number of coal miners in the CBP is similar to that derived from the mine-level data offered by the Mine Safety and Health Administration (MSHA).

[6]Coglianese et al. (2020) show that 92 percent of the total decline in coal production between 2008 and 2016 could be attributed to the declining price of natural gas relative to coal, with environmental regulations accounting for an additional six percent.

[7]Notably, this period of declining demand for coal is not the first "shock" to affect the industry. Coal has been exposed to several boom and bust cycles throughout its history, largely driven by macroeconomic factors affecting demand. Several papers, for example, investigate the consequences of the large increase in demand for coal during the 1970s and the subsequent collapse of the 1980s on exposed coal communities in Appalachia (Black et al., 2002, 2003, 2005).

[8]This restriction omits about 35 percent the original sample 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.

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.

1985. Again, we limit the analyses to those workers who worked full-time in all five years preceding the recent coal shock.[9] For all statistics and analyses that consider the evolution of earnings and AGI, we omit the very small number of workers who report negative AGI from the sample.

3 The coal workforce

We begin by describing the characteristics of coal workers, including demographic characteristics, a summary of earnings and income, and their location of residence. We then describe job separations from coal mining establishments and present descriptive evidence on the evolution of earnings and income with these separations.

3.1 Who works in the coal industry?

General demographic and earnings characteristics of coal and non-coal workers are provided in Table 1. Age, earnings, and Adjusted Gross Income (AGI) refer to 2011 values, with earnings and AGI adjusted to 2019 dollars using the CPI-U deflator. The statistics in column 1 are for 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 sample in column 2 is all workers born between 1955 and 1985 who worked "full-time" for a coal mining establishment in every year between 2007 and 2011.[10] As detailed in Section 4, this group of coal workers —- with substantial tenure in the industry and greater exposure to the subsequent coal shock — serves as the "treated" group of workers in our quasi-experimental analysis. Column 3 provides summary statistics for workers born between 1955 and 1985 who worked full-time between 2007 and 2011, but who did

[9]The construction of this sample is detailed in Section 4, In our empirical specification, we control for a rich set of worker and firm-level characteristics so as to compare the earnings and employment trajectories of coal workers to those of observatiobally similar control workers. In robustness checks, we instead construct an ACS sub-sample by taking a 20-percent sample of ACS respondents born between 1955 and 1985 who live in a specified bandwidth outside of coal counties to ensure that control workers' earnings and employment outcomes are not influenced by the local spillover effects of adverse labor demand shocks. Our conclusions are insensitive to precise approach used to select the ACS sub-sample.

[10]We define a worker as "full-time" if their earnings in a given year are greater than what they would earn by working 1,600 hours (about 30 hours per week) at the federal minimum wage. In 2011, this means that they report earning at least $11,600.

Table 1: Characteristics of workers (2011)

	(1) All coal workers	(2) FT ("treated") coal workers	(3) FT ("control") workers	(4) Entire FT sample
Male	92.73	95.92	67.84	73.31
	(25.96)	(19.79)	(46.71)	(44.23)
Non-Hispanic white	91.29	95.12	81.63	84.25
	(28.20)	(21.55)	(38.72)	(36.43)
College degree	9.95	6.79	37.67	35.36
	(29.93)	(25.15)	(48.46)	(47.81)
Homeowner	84.00	90.78	81.32	82.03
	(36.66)	(28.94)	(38.97)	(38.39)
Age	40.6	43.0	41.6	41.9
	(14.6)	(9.0)	(8.9)	(8.9)
Wages ($10,000s)	63.84	92.02	76.64	79.64
	(312.9)	(47.67)	(148.2)	(134.8)
AGI ($10,000s)	94.61	110.9	110.4	110.5
	(1276)	(103.5)	(424.2)	(383.3)
Observations	218,000	29,500	123,000	152,000

Source: ACS 2005–2021 linked with the Environmental Impacts Frame, IRS W-2s and Census Business Register. 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 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 includes all workers who worked for a coal mining establishment as their primary source of earnings in any year during the 2005 to 2021 period. The sample in column 2 restricts to individuals working full-time for a coal mining establishment in each year from 2007–2011, defined in the text. The sample in column 3 is "control" workers working full-time in each year from 2007–2011 but working for a coal mining establishment in fewer than five of these years. The sample in column 4 includes all individuals working full-time in each year from 2007–2011 (including both coal and non-coal workers). Earnings and AGI have been adjusted to 2019 dollars. Standard deviations are in parentheses.

not work for a coal establishment in all five of these years.[11] This group of workers — with less exposure to the recent coal shock — serves as the "control" group in our quasi-experimental analysis, and is drawn from the merged coal worker panel and the panel constructed from a random sub-sample of 2010 ACS respondents. The sample in column 4 consists of the summation of the workers described in columns 2 and 3, and thus includes the entire sample of workers born between 1955 and 1985 who worked full-time in all years from 2007 to 2011

[11]The sample in column 3 includes some workers who worked for a coal mining establishment during the study period, but they worked for a coal mining establishment in fewer than five of the years between 2007 and 2011.

Comparing the statistics in columns 2 and 3, full-time "treated" coal workers are more likely to be male, white, and less likely to have a college degree than other full-time workers less exposed to the macroeconomic decline in coal. Only 7 percent of full-time coal workers born between 1955 and 1985 in 2011 had a college degree, compared to 38 percent of other full-time workers.[12] 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 previews the potentially disruptive consequences that contractions in demand for coal may have for exposed workers. 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 as well, 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.[13] 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 concentrated. 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. This "right tail" is predominately composed of counties in Eastern Kentucky and West Virginia. As a share of the U.S. coal workforce in 2011, the

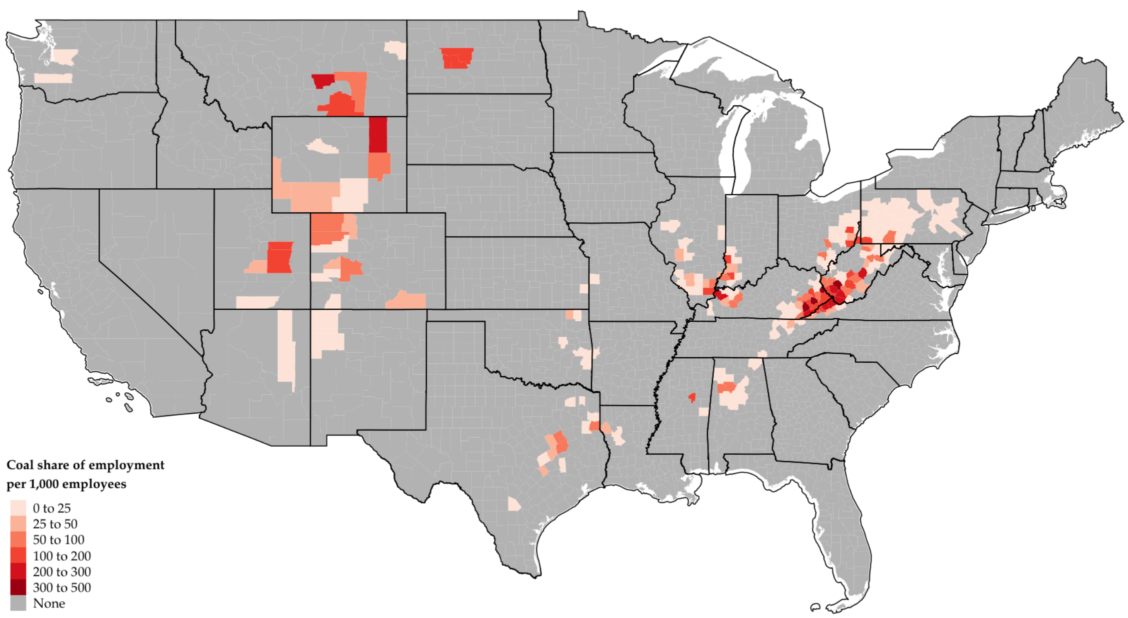
[12] Educational attainment, homeownership, and sex reported in Table 1 are drawn from the subset of workers who took this survey between 2005 and 2021 and thus they are based on the year in which the respondent took the survey, which may differ from 2011.

[13] 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.

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 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.

Figure 2: Coal share of employment, 2011



Note: 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

[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.

3.2 Job separations in coal

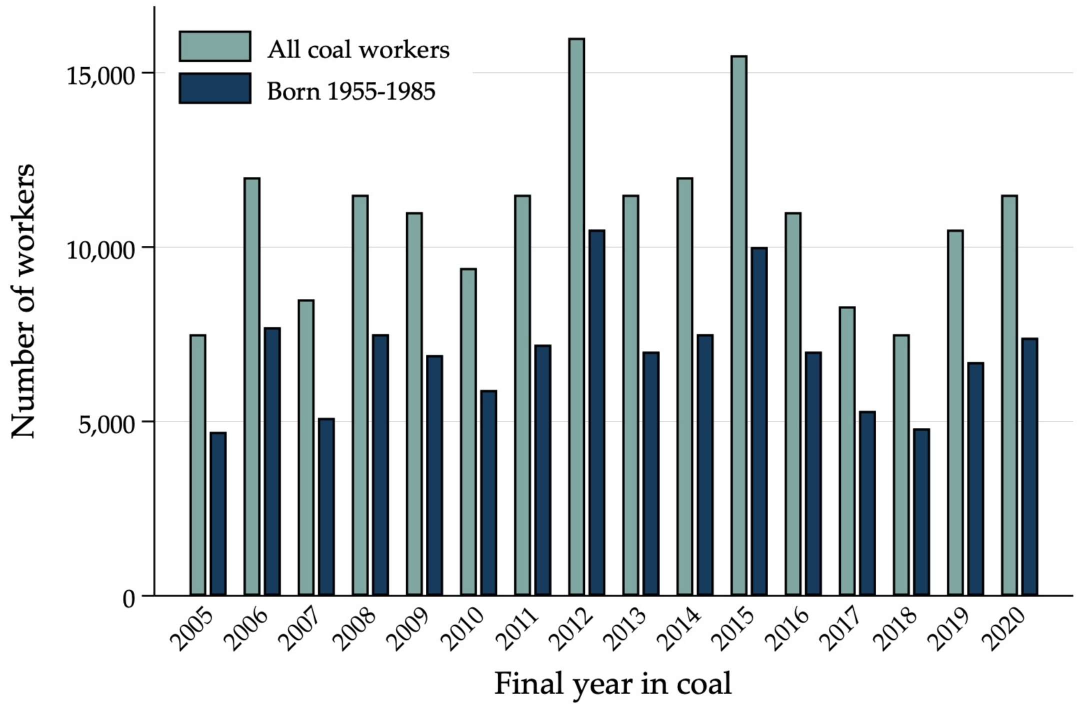
As indicated by Figure 1, the number of coal workers declined substantially over the 2005–2021 period, although these losses were driven by those occurring following its 2011 peak. Here, we describe separations from coal mining establishments, including the number and frequency of these separations as well as descriptive evidence on the evolution of earnings and income prior to and following these separations.

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 during the 2005–2021 period, 174,000 (80 percent) separated from coal at some point during the 17-year period. 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). Many workers transition into and out of working for a coal mining establishment over the sample period. To summarize the timing of these separations, we define the *final* separation as the final year in which the worker transitions away from coal over the study period. Figure 3 shows a histogram of these final separations for the universe of coal workers in the U.S. who separated from the industry at least once over the 17-year period. The year indicates the final year in which the worker's primary earnings were drawn from the coal mining industry. We omit the final year of our sample, 2021, to avoid the mechanical classification of it being a worker's final year in coal.

As indicated in Figure 3, 2012 was the peak "final" year in coal mining, followed closely by 2015. However, the frequency of separations was relatively evenly distributed across most other years. This is consistent with the conclusions drawn from Figure 1, which showed that the decline in total coal mining employment was relatively steadily after 2011.

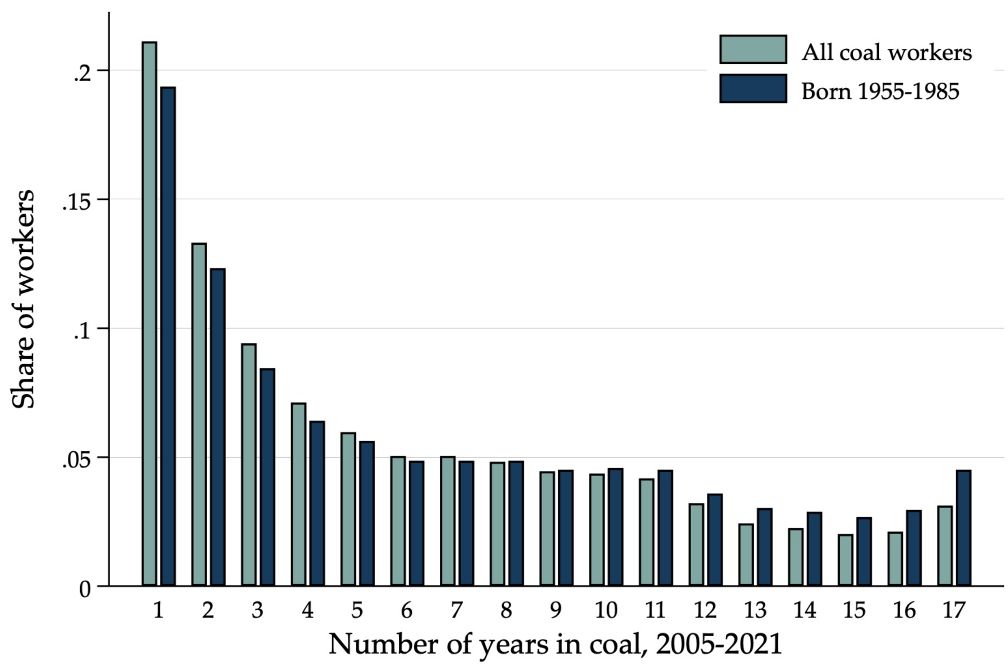
Figure 3: Final separations from the coal industry by year, 2005–2020



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 separated 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. "Born 1955–1985" 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 the aggregate number of workers employed by the coal mining industry in any given year largely understates the number of workers who have at some point relied upon the industry as a major source of labor income. The full sample of workers whose primary source of earnings came from the industry in any year between 2005 and 2021 (218,000) is over twice as large as the number of coal workers employed in 2011 (99,500), when the industry reached its contemporary peak. It is over 5 times as large as the number of coal workers employed today. This suggests that there is some degree of churn in the coal workforce, with many workers only employed in the industry for brief spells. Figure 4 plots the total number of years a worker was employed in coal mining as the primary source of earnings over the 2005–2021 period. Over half of the workers worked for a coal mining establishment as their primary employer for fewer than five years over the 17-year period. This conclusion is insensitive to restricting to the primary sample of workers born between 1955 and 1985. Of this restricted sample, 47 percent worked in coal for fewer than five total years over the 15-year period. This figure likely understates total tenure, as many workers might continue working for the industry in a part-time capacity while earning greater income at a non-coal employer, and many workers likely have employment histories in the industry that precede 2005. Still, this indicates that a large share of workers are only marginally attached to the industry.

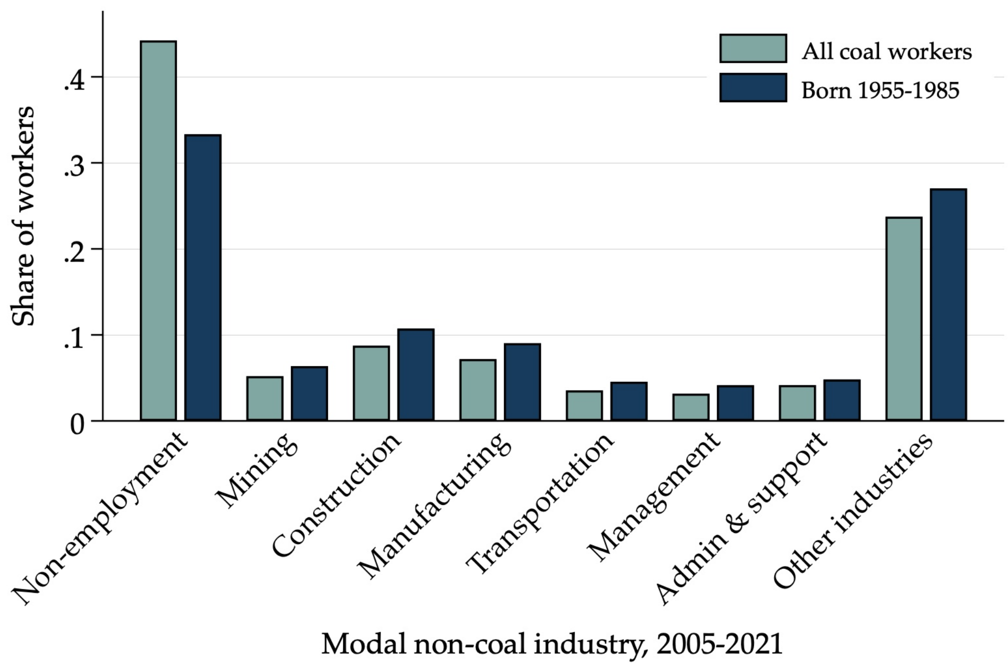
Figure 4: Number of years worked in coal, 2005–2021



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. "Born 1955–1985" 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.

To what extent were these non-coal years characterized by non-employment rather than employment in other industries? If the latter, what industries served as the primary sources of earnings? For each worker in the panel, we determine the modal 2-digit NAICS industry that served as the worker's primary source of earnings across non-coal years. We include non-employment as its own category, defined as reporting no W-2 earnings. For example, if the worker's primary earnings came from coal for eight years, manufacturing for five years, and management for two years, the modal non-coal industry would be classified as manufacturing. If the worker's primary earnings came from coal for three years, construction for two years, and the worker reported no W-2 earnings in the remaining ten years, the modal industry would be classified as non-employment.

Figure 5: 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. "Born 1955–1985" 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.

Figure 5 reports the major industries from which coal workers received earnings in non-coal years. We identify the top six 2-digit industries (sectors) that served as the modal, non-coal industry for coal workers, and group the remaining industries into the "other" category. We include non-employment as its own "industry." For 44 percent of all coal workers, most non-coal years were characterized by non-employment, defined as reporting earning zero wages to the IRS. Particularly young individuals who are enrolled in school at the beginning of the period or older individuals who enter retirement by the end of the period could confound interpretation of this result. Recalculating the modal non-coal industry for coal workers born between 1955 and 1985 reveals similar patterns. Among this group of coal workers born between 1955 and 1985, non-employment remains the modal non-coal "industry" for the plurality of individuals (33 percent). Besides non-employment, the most common non-coal industries are construction (10%), manufacturing (9%), and mining (6%).[15]

The evidence presented in this section, indicating that coal employment has declined substantially since its peak in 2011, is consistent with other work that uses publicly available data to examine the evolution of coal mining employment in recent decades. The richness of our data allows for several other insights. First, aggregate statistics substantially understate the number of individuals who relied on the industry as their primary source of earnings at some point. The number of individuals in our coal worker panel is more than double the number of workers employed in coal during its peak year over the sample period. Second, many workers appear only marginally attached to the industry, working for coal for relatively few years over the 2005–2021 period. Finally, non-employment is highly prevalent. The modal employment activity for the plurality of individuals in our coal worker panel during the years in which they did not work for coal was non-employment, again, defined as reporting no W-2 earnings.

3.2.2 Descriptive evidence on the evolution of earnings and income with separations

How do earnings and income evolve following firm separations in the coal industry? In this section, we offer descriptive evidence on this evolution, focusing on the sample of 142,000 coal workers born between 1955 and 1985. To summarize the evolution of earnings and income from each separation we describe the impulse response function using the local projections approach (Jordà, 2005, 2023). Specifically, for each worker-year observation, we define the difference in outcomes at different time horizons, compared to $t-1$:

[15] These correspond to 2-digit NAICS codes 23, 31–33, and 21, respectively.

$\Delta y_{i,t+h}$. This allows us to explore multiple separation events, rather than restricting to the "first event" a worker experiences, or requiring us to "stack" events for each worker. For a given switching event at time t, $Switch_{it}$, we then trace out the conditional mean of income or earnings in the periods before and after the switch, relative to $t-1$. We define a separation or "switch" event as one in which a worker "switches" firms *and* switches from working in coal to not working in coal.[16] Non-employment is classified as a firm category, so a worker will be characterized as "switching" firms if he or she transitions into non-employment.[17]

Our empirical specification for this descriptive analysis reflects a bivariate regression estimated for each time horizon, h,

$$\Delta y_{i,t+h} = \beta^h Switch_{it} + \varepsilon_{it} \tag{1}$$

where $\Delta y_{i,t+h}$ is the change in outcome y for worker i in year $t+h$ relative to $t-1$. We consider two outcome variables: W-2 earnings (wages) and adjusted gross income (AGI).[18] $Switch_{it}$ is an indicator equal to one if worker i switches firms away from coal in year t, and zero otherwise.[19] We cluster standard errors at the Commuting Zone level. Our results are robust to two-way clustering at the worker- and firm-level. We estimate equation 1 using the primary sample of coal workers with non-negative AGI born between 1955 and 1985.

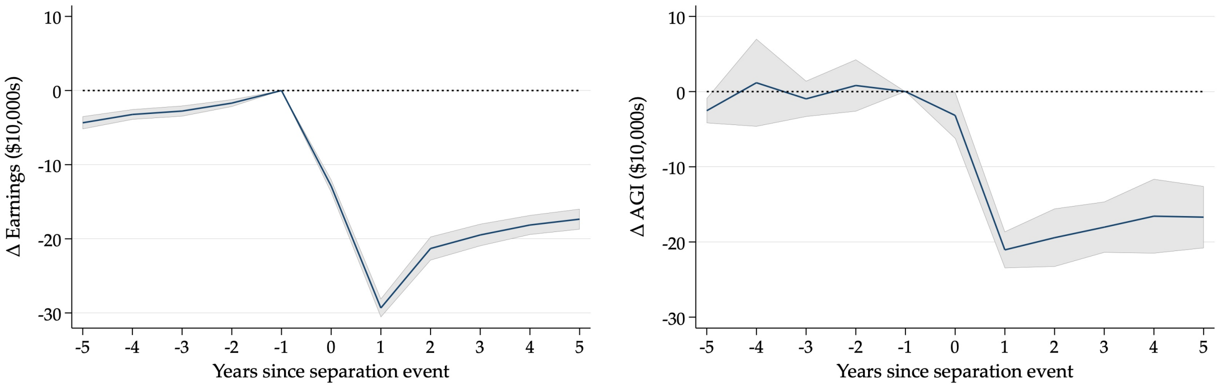
[16] This is a relatively conservative measure of separation from the coal industry. Not included in this definition are workers who switch from a coal establishment to a non-coal establishment but remain employed at the same firm. Because we match workers to establishments based on the EIN codes of 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.

[17] 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.

[18] Earnings and AGI are missing for worker-year observations in which the worker reported no W-2 or 1040, respectively. Observations for which both variables are missing are omitted. We impute AGI as reported earnings when AGI is missing but earnings are observed. We impute earnings as zero when earnings are missing but AGI is observed. Our results are robust to not imputing these values.

[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.

Figure 6: Separations from Coal and the Evolution of Earnings and Income



(a) W-2 Earnings (b) Adjusted Gross Income

Note: This figure plots the bivariate relationship between a firm separation and the evolution of earnings and income 5 years on either side of the separation event. The event is defined as the year of separation. Separations may include switches into non-employment. The sample is limited to workers born between 1955 and 1985 with non-negative AGI. Each estimate is the result of a separate bivariate regression estimated for each time horizon as presented in equation 1. Panel A) presents the association between a separation event and W-2 earnings. Panel B) presents the association between a separation event and adjusted gross income. 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 6 presents the evolution of earnings and income following a coal separation event. We document that firm separations from coal mining are associated with relatively large declines in earnings and income that persist well beyond the initial separation event. In the year of separation, workers experience an immediate decline in earnings of nearly $13,000 relative to the previous year. Overall income appears to be buffered in the separation year, which likely reflects a combination of unemployment insurance, severance pay, and “hardship withdrawals” from 401k accounts. Both earnings and income in the following period continue to fall and do not fully recover over the next 5 years. Peak earnings losses are nearly $30,000 per year in the year after and recover to around $17,000 lower than the year prior to separation five years after the event. Adjusted gross income declines by $21,000 and remains persistently lower in the years following separation. We do not observe the number of hours or months worked and so cannot distinguish the extent to which workers’ earnings trajectories are explained by reductions in work versus reductions in wage rates. In Appendix Figure A2, we present estimates analogous to those in Figure 6 that include controls for year, Census region, and basic worker-level covariates (age and gender). The inclusion of these controls has very little effect on the conditional means.

These patterns are descriptive, capturing the unconditional variation in the data rather than the causal effects of separation. Workers might leave the industry for better job opportunities elsewhere, introducing an upward bias in the relationship between displacement and subsequent earnings. 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. Descriptively, however, the evidence presented indicates that individual workers who separate from jobs in the coal mining industry experience relatively large earnings and income losses which ultimately fail to recover to their pre-separation peaks. In the following section, we explore this conjecture more systematically.

4 Quasi-experimental Evidence: Margins of Adjustment

The "coal shock" has been a multi-year episode of waning demand for the resource, to which the industry and workers likely adapted and adjusted along various margins. Job loss is one consequence of declining demand, but the characteristic job loss event study is not well-suited to capture all of the possible transitional dynamics associated with the coal shock because it is only one margin of adjustment. Drawing upon the research design introduced by Autor et al. (2014) – who evaluate the consequences of rising import penetration on affected workers – we characterize the incidence of the coal shock on cumulative earnings, years of employment, and changes in earnings when employed. We also explore changes in earnings within the firm or at other firms within the same industry, industry switching, and location switching. We evaluate how the consequences of the coal shock are influenced by these different margins of adjustment. Here, we focus on the evolution of W-2 earnings (wages) and employment, but our conclusions are qualitatively similar if we look at broader measures of income as well.

4.1 Empirical approach

Our empirical approach leverages the fact that some workers are more or less exposed to the large-scale, macroeconomic decline in demand for coal beginning after 2011 (i.e., the "coal shock") based on their labor market experience in, or attachment to, the industry. Workers with greater tenure at coal mining establishments in the years just prior to coal's decline (2007–2011) are more "attached" to the industry, and therefore relatively more exposed to the coal shock that followed.[20] We examine how this measure of exposure to the coal shock affects cumulative earnings and employment between 2012 and 2019 by estimating the following specification for all workers who worked "full-time" between 2007 and 2011:

$$E_{i\tau} = \beta_0 + \beta_1 \mathbb{1}[Coal_{i,2007\text{-}11}] + X'_{i,0}\gamma + \delta_r + \varepsilon_{i\tau} \quad (2)$$

In equation 2, $E_{i\tau} = \sum_{t=2012}^{t=2019} \frac{E_{it}}{\overline{E}_{it_0}}$ reflects the cumulative earnings of worker i between 2012 and 2019, normalized by his or her 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 can observe how exposure to the shock influences the evolution of a worker's earnings. We also consider several other 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 the cumulative number of years the worker lives in his or her 2011 commuting zone (CZ) between 2012 and 2019.

We limit our analysis to individuals in the combined coal and non-coal panel of workers with non-negative AGI born between 1955 and 1985 and who worked "full-time" in all five of these pre-shock years (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 at the federal minimum wage. We also omit a small number of workers who died during the sample

[20]This identification strategy is similar in spirit to Autor et al. (2014), which leverages the fact that some workers were more or less exposed to the effects of rising import penetration based on their initial industry of employment.

period and whose location could not be determined, leaving a final sample of around 152,000 individuals.[21] The primary independent variable of interest is $\mathbb{1}[Coal_{i,2007\text{-}11}]$, a dummy variable indicating whether worker i's primary employer was a coal mining establishment in all five pre-shock years. In alternative specifications, we define the primary independent variable as both a continuous and a binned variable indicating the number of years between 2007 and 2011 for which the worker's primary employer was a coal mining establishment, as detailed in Appendix Section B.2. The conclusions of our analysis are not sensitive to this choice of specification. Of the final sample, 29,500 individuals worked full-time for a coal mining establishment in all five pre-shock years, and thus serve as the "treated" group of workers most exposed to the subsequent coal shock.[22] The remaining "control" workers have less or no attachment to the coal industry in these pre-shock years and are thus less exposed to the subsequent coal shock.[23] We control for a rich set of worker-level controls $X_{i,0}^{'}$, which includes the worker's age, 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 his or her 2011 firm between 2007 and 2011, 8 bins of establishment size (based on 2011 establishment), and a dummy variable indicating whether the worker ever worked for a coal establishment during our panel. We also include Census region fixed effects, δ_r.[24] 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.[25]

This identification strategy compares workers who are ex-ante observationally similar, but have varying attachment to the coal mining industry in the pre-shock period, and

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

[22]Characterizing pre-shock years as 2005 to 2011 and limiting the sample to workers who worked full-time during this entire seven-year period has no substantive impact on the conclusions.

[23]The vast majority of control workers have *no* attachment to (i.e., tenure in) the coal industry in the five pre-shock years, and a small fraction worked in the coal industry for fewer than five years.

[24]In Appendix Section B.1, we include an additional control variable that captures a worker's spatial proximity to local coal shocks in other labor markets. The conclusions drawn from this specification are broadly similar to those drawn from the primary analysis.

[25]We can also cluster on the worker's CZ in 2011 to allow for correlation in the error terms among workers who are initially employed in the sample labor market. This does not change the interpretation of the coefficients.

thus varying exposure to the subsequent macroeconomic decline in coal demand. The main identifying assumption underlying this strategy is conditional independence – conditional on the rich set of individual-level control variables, exposure to the coal shock is as good as randomly assigned. That is, after accounting for differences in observable worker characteristics including age, pre-period wages, and pre-period work experience, our strategy assumes 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, and observed differences in earnings and employment trajectories between 2012 and 2019 are attributable to the fact that the macroeconomic shock diminished demand for coal workers as opposed to similar workers working in other industries.

One might imagine that the most tenured coal workers could be *less* exposed to the adverse consequences of contractions in the coal industry compared to coal workers with slightly less tenure in terms of years worked for the industry, if the most tenured workers are the last to experience pay cuts or layoffs. Omitting workers whose primary employer was a coal mining establishment in at least one year, but fewer than five years, between 2007 and 2011 does not substantively impact the estimates presented below. Given that these workers are partially exposed to the coal shock, and thus may also experience its resulting employment and earnings consequences, our primary estimates likely reflect a lower bound of the consequences of coal shock exposure.[26] The conclusions are also robust to defining exposure based on alternative measures of tenure in the pre-shock years, as detailed in Appendix Section B.2.

Another potential concern is that while treatment is defined at the individual level, given the high spatial concentration of coal mining activity, it is possible that some other (non-coal) demand shock differentially affected highly coal-dependent communities over this period. For example, if coal-rich regions were differentially exposed to the Great Recession, tenured coal workers might suffer from the persistent consequences of this

[26]The magnitude of the coefficient estimates increases when these partially exposed workers are omitted from the control group, suggesting that the reported estimates do indeed reflect a lower bound on the consequences of the coal shock on all exposed coal workers.

economic event on employment absent the macroeconomic decline in coal (Yagan, 2019). While this could be a concern in other settings, 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. Further, the inclusion of state fixed effects will absorb any idiosyncratic state-level shocks that might influence earnings and employment. If residual within-state variation in the long-run effects of the Great Recession affected coal workers more than non-coal workers, we would overstate the effect of the coal shock, and vice-versa.

The coefficient estimate of β_1 measures the effect of greater exposure to the coal shock, defined based on a worker's tenure in the coal industry during the pre-shock years, on the outcome of interest. Importantly, it does *not* measure the effect of dislocation from the industry itself. Some tenured coal workers will continue working in the industry. This approach enables us to determine the degree to which exposure to the coal shock induces reduced employment and earnings, and thus the degree to which workers are affected along both extensive and intensive margins. If workers can costlessly transition into new jobs in other industries or labor markets, we should expect aggregate earnings and employment losses to be minimal. If, however, coal workers have developed industry-specific skills or face substantial labor market or migration frictions, transitional costs may be substantial.

4.2 Results

Table 2 reports the central estimates of β_1 in equation 2, reflecting the association between "coal shock" exposure and cumulative earnings (column 1), the number of years with positive earnings (column 2), earnings per year (column 3), and the number of years that the worker lives in their 2011 CZ (column 4) – an indicator for differential mobility. The mean and standard deviation of each outcome variable is presented underneath each coefficient estimate.

The estimates presented in Table 2 show that greater exposure to the "coal shock,"

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	(4) # of years in 2011 CZ
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.431***	-0.321***	-0.157***	0.194***
	(0.087)	(0.035)	(0.010)	(0.040)
Outcome mean (SD)	8.05 (3.71)	7.45 (1.43)	1.06 (0.43)	7.02 (2.20)
Controls	✓	✓	✓	✓
Region FE	✓	✓	✓	✓
Observations	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. 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<0.01, ** p<0.05, * p<0.1

as defined by tenure in the industry in the years preceding the shock, is associated with relatively large earnings losses between 2012 and 2019. Compared to observationally similar workers who were less attached to the industry in the pre-shock period and thus less exposed to the shock, exposed coal workers experience a decline in cumulative earnings that is 1.43 times their 2007–2011 annual wage over the 2012–2019 period – nearly a year and a half's worth of annual earnings (column 1). The negative coefficients in columns 2 and 3 show that this cumulative earnings effect can be accounted for by both reductions in the number of years workers are employed (the extensive margin) as well as reductions in earnings when employed (the intensive margin). We estimate that, on average, more exposed coal workers experienced 0.32 fewer years of work between 2012 and 2019 compared to observationally similar workers (column 2), and a 16 percent reduction in earnings during the years that they are employed (column 3).[27] It is important to note

[27]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, but the sample sizes are rounded in line with Census disclosure rules to the same value.

that we are unable to distinguish whether earnings reductions are driven by reductions in working hours or reductions in earnings per hour worked. In column 4, we estimate that, on average, more exposed workers spend 0.19 additional years – approximately 10 weeks – living in their 2011 CZs between 2012 and 2019. Comparing the coefficient estimates to the outcome means helps to garner a sense of magnitude, especially for outcomes expressed in years. For example, comparing the coefficient on the number of years with positive earnings (-0.32) to the outcome mean (7.45) suggests that exposure to the coal shock is associated with about a 4 percent reduction in years of employment. Likewise, exposure to the coal shock is associated with a 2.7 percent increase in the number of years spent living in the 2011 CZ. While statistically significant, the magnitude of this effect is small, indicating that the geographic mobility of exposed coal workers is not substantively different from observationally similar workers.

4.2.1 The role of reallocation

Does reallocation across industries or regions modify the aggregate earnings and employment losses experienced by exposed coal workers? In Table 3, we decompose the total observed earnings and employment effect of exposure to the coal shock (replicated in column 1) into total earnings or years of employment between 2012 and 2019 observed at the worker's initial (2011) employer (column 2), total earnings or years of employment observed at other firms in the same 2-digit industry (column 3), and total earnings or years of employment observed outside of the 2-digit industry entirely (column 4). As an illustration, consider a worker who spends 2 years at the same (2011) firm, before separating and becoming unemployed for a year and then moving into a different industry for the remainder of the 2012–2019 period. Their cumulative earnings and cumulative years of employment while at the same firm will be captured in column 2. They will have zero cumulative earnings or cumulative employment in column 3 because they exited the industry, and their earnings and years of employment from their remaining years will be reflected in the outcome variable measured in column 4. Alternatively, a worker may move to a different firm within the same industry in 2012 and remain within the industry for the remaining period. All of their earnings and employment will be reflected in column 3. In each case, we compare treated workers to control workers in the same category, e.g., in column 3 we compare cumulative earnings and employment during the years in which coal workers are at different firms in the "Mining, Quarrying, and Oil and Gas Extraction" sector to the cumulative earnings and employment of control workers during which they are at different firms but in their 2011 2-digit industry.

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. These estimates are not additive for Panel C (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 those in columns 1 through 3 of Table 2.

We estimate that the workers most exposed to the coal shock experience substantially reduced earnings *outside* of their initial 2-digit industry, but not *within* their initial 2-digit industries. The point estimates in columns 2 and 3 of Panel A indicate that more exposed coal workers earned almost an additional year's worth of earnings between 2012 and 2019 from their initial (2011) industry compared to control workers, with this effect driven by roughly equal parts years spent at the same firm in the same industry and years spent at a different firm in the same industry. The estimates in columns 2 and 3 of Panel B indicate that this is driven by additional years of employment. We estimate that more exposed coal workers worked an additional 0.7 years at both their initial firms and at different firms in the same industry between 2012 and 2019 compared to control workers. They do, however, experience a 12 to 13 percent reduction in earnings per year of employment within their initial industry compared to their average annual earnings from 2007 to 2011. This indicates that the intensive margin – reduced earnings while employed within the industry – is a relevant margin of adjustment. Together, the estimates in columns 2 and 3 indicate that exposed coal workers earn and work more in aggregate within "Mining, Quarrying, and Oil and Gas Extraction" than comparable workers earn and work in their initial industries between 2012 and 2019, but they experience reduced earnings per year of employment. The estimates in column 4 reveal that the reductions in

Table 3: Exposure to coal shock and earnings and employment by employer and industry

	(1)	(2)	(3)	(4)
	All employers	**Same industry**		**Diff. industry**
		Same firm	Diff. firm	
Panel A: Cumulative earnings				
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.431***	0.452***	0.467***	-2.349***
	(0.087)	(0.150)	(0.135)	(0.112)
Outcome mean (SD)	8.05 (3.71)	4.03 (3.77)	1.46 (2.79)	2.55 (3.79)
Panel B: Cumulative employment				
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.321***	0.727***	0.701***	-1.749***
	(0.035)	(0.161)	(0.134)	(0.088)
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				
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.157***	-0.119***	-0.139***	-0.297***
	(0.010)	(0.014)	(0.014)	(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	85,500

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 2–4 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<0.01, ** p<0.05, * p<0.1

cumulative earnings and employment observed in column 1 are driven by years in which workers are observed outside of their initial 2-digit industries, which includes years of non-employment. Exposed coal workers experience a decline in cumulative earnings that is 2.35 times their 2007–2011 annual wage over the 2012–2019 period – almost two and a half years' worth of annual earnings – outside of their initial 2-digit industries. This is almost as large in magnitude as the sample mean (2.55). This can be explained by both large reductions in the years of employment – 1.75 fewer years – and an almost 30 percent reduction in earnings per year of employment. The magnitude of the extensive margin response appears large. Compared to the average across the entire sample (2.45 years), the coefficient estimate for cumulative employment in column 4 suggests that exposed coal workers spent about 71 percent fewer years employed in different industries.

One advantage of our data is that we are able to identify a worker's location in all years of the data, including years of non-employment. Column 4 of Table 2 provided evidence to suggest that exposed coal workers are marginally less mobile than observationally similar workers. In Table 4, we evaluate the extent to which employment intersects with geographic mobility to attenuate the cumulative earnings losses among exposed coal workers. Here, we decompose the total observed worker-level effect of the coal shock exposure on earnings and employment (column 1) into years observed within the CZ in which the worker was employed in 2011 (column 2) and years observed in a different CZ (column 3).

The negative coefficients in all cells imply that, on average, exposed coal workers experience reduced earnings, spend fewer years employed, and receive fewer earnings per year employed, compared to observationally similar workers, whether they remain in their 2011 labor market or not. Geographic mobility alone is not sufficient to fully mitigate the consequences of the coal shock. These estimates do not imply, however, that geographic mobility is unimportant. Coal mining is highly spatially concentrated, and most coal communities lack comparable employment opportunities. If coal workers have highly industry-specific skills and few alternative local employment opportunities that reward these skills, relocation might improve earnings and still yield reduced cumulative earnings compared to less exposed workers who relocate. Comparing the estimates in columns 2 and 3 of Panel A demonstrates that the negative effect of coal shock exposure on cumulative earnings received *within* a worker's 2011 CZ is about twice as large as the effect on cumulative earnings received outside of the worker's CZ, i.e., approxi-

Table 4: Exposure to coal shock and earnings and employment by location

	(1) **All CZs**	(2) **Same CZ**	(3) **Different CZ**
Panel A: Cumulative earnings			
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.431***	-1.025***	-0.406***
	(0.087)	(0.090)	(0.051)
Outcome mean (SD)	8.05 (3.71)	7.04 (3.91)	1.00 (2.78)
Panel B: Cumulative employment			
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.321***	-0.098	-0.223***
	(0.035)	(0.055)	(0.039)
Outcome mean (SD)	7.45 (1.43)	6.57 (2.41)	0.89 (2.07)
Panel C: Earnings per year of employment			
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.157***	-0.150***	-0.178***
	(0.010)	(0.010)	(0.014)
Outcome mean (SD)	1.06 (0.43)	1.05 (0.41)	1.08 (0.63)
Controls	✓	✓	✓
Region FE	✓	✓	✓
Obs. (Panels A and B)	152,000	152,000	152,000
Obs. (Panel C)	152,000	147,000	30,500

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 2–3 decompose these effects into employment and earnings obtained in the 2011 CZ of residence versus other CZs. 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<0.01, ** p<0.05, * p<0.1

mately two-thirds of the aggregate effect of exposure to the "coal shock" on cumulative earnings is driven by years spent inside of the worker's 2011 CZ versus outside of the CZ. However, comparing these coefficients to the sample means suggests that exposed coal workers earned much *less* in different labor markets in relative terms. The decline in cumulative earnings reflects about a 14 percent decline over the sample mean for years spent in the same CZ, versus a 40 percent decline over the sample mean for years spent in a different CZ. This is both thanks to a large extensive margin response — exposed coal workers spend about one-quarter of a year less, or 25 percent fewer years than the sample mean — and intensive margin response — exposed coal workers earn less during the years in which they are employed in different CZs.

In Table 5, we investigate both forms of reallocation simultaneously. We decompose the total observed worker-level effect of coal shock exposure (column 1) into total earnings or years of employment observed within the worker's 2011 industry and CZ (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 industry and CZ.

The coefficients in Table 5 provide a more nuanced assessment of the role that sectoral and geographic mobility play in attenuating or exacerbating the earnings and employment declines associated with exposure to the coal shock. As in Table 3, remaining in one's 2011 industry offsets the cumulative earnings and employment declines for exposed workers. This is true whether employment occurs within or outside of the initial CZ.[28] Column 3 indicates that cumulative earnings and employment losses for exposed coal workers are driven by years in which workers remain in their 2011 CZ but exit their 2011 industry. Exposed coal workers earn much less and work fewer years in different industries within their initial CZs than observationally similar workers. The point estimates in Panel B imply that exposed coal workers spend 1.4 fewer years employed in their initial CZ but outside of their 2011 industry (column 3), and about 0.3 fewer years employed outside of their CZ and outside of their 2011 industry (column 5). The average number of years employed in the same CZ but a different industry (2 years) is over four times that employed in different CZ and a different industry (0.45 years), and thus this

[28]While the magnitude of the coefficient is much larger for years employed within the 2011 CZ (column 2) than outside of the CZ (column 4), comparing these coefficients to the sample mean suggests that exposed coal workers spend about 26–28 percent more years employed in their initial (2011) industries relative to the sample mean than observationally similar workers, regardless of the labor market in which the employment takes place.

Table 5: Exposure to coal shock and earnings and employment 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					
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.431***	0.860***	-1.885***	0.059*	-0.465***
	(0.087)	(0.109)	(0.105)	(0.029)	(0.031)
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					
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.321***	1.313***	-1.411***	0.115***	-0.338***
	(0.035)	(0.101)	(0.086)	(0.024)	(0.022)
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					
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.157***	-0.123***	-0.297***	-0.129***	-0.314***
	(0.010)	(0.012)	(0.021)	(0.015)	(0.016)
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<0.01, ** p<0.05, * p<0.1.

extensive margin response is quite similar in relative terms across labor markets.[29] That aggregate losses are driven by years in which workers remain in their 2011 CZ but are not employed in their initial industry likely reflects the limited alternative employment

[29]Relative to the sample mean, the point estimates suggest that exposed coal workers spend about 70 percent fewer years employed in the same CZ but a different industry, and about 75 percent fewer years employed in a different CZ and a different industry.

opportunities available in many coal communities.

While the estimates in Panel B indicate that the extensive margin (non-employment) contributes to cumulative earnings losses, earnings losses during years of employment are also important. Panel C reveals that exposed coal workers suffer declines in earnings per year across all industry-location pairs, and the reduction in earnings per year employed in a different 2-digit industry is nearly three times larger than the reduction within the same industry, regardless of whether it is observed inside or outside of a worker's initial CZ. While exposed coal workers spend much less time employed in different industries *outside* of their 2011 CZ relative to the sample means, they suffer relatively large earnings declines in years in which they are employed in these different industries outside of their initial labor markets. Taken together, these results imply that geographic mobility does not play a large role in shaping the intensive margin of adjustment – conditional on switching industries, former coal workers suffer similar earnings losses inside and outside of their initial CZs. Thus, encouraging relocation or reducing barriers to mobility is likely insufficient to attenuate cumulative losses. Rather, this evidence is consistent with the presence of firm- or industry-specific skills that are destroyed upon displacement from the industry (Neal, 1995).

4.2.2 The role of industrial sector in offsetting losses

The evidence so far indicates that workers more exposed to the large-scale decline in demand for coal beginning in 2011 suffered large earnings and employment losses if they did not continue working in mining and extraction activities. In this section, we explore the extent to which other industries offer differential opportunities to separated coal workers. Specifically, we explore whether the consequences for workers who move into different industries depend on whether industries are "high wage" and whether they depend on local demand.

We first explore whether entering other "high-wage" industries attenuates the aggregate earnings losses. In Table 6, we decompose the total observed worker-level effect of coal shock exposure (column 1) into earnings and employment changes by geographic location, industry, *and* the industry wage level. Columns (1), (2), and (5) remain the same as columns (1), (2), and (4) from Table 5. We define "high-wage" industries as those that pay the same *or more than* the "Mining, Quarrying, and Oil and Gas Extraction" industry, 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.[30] 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).[31]

Table 6 shows that coal workers' aggregate losses are *not* attenuated by earnings and employment observed in these "high-wage" industries. If anything, cumulative losses are driven by years observed in higher-wage industries. This does not imply that coal workers who switched into these industries did not experience earnings gains relative to working in coal. Rather, it implies that exposed coal workers experienced aggregate losses in cumulative earnings and employment in these industries compared to less exposed workers. We observe that it is rare for coal workers to transition into these "high-wage" industries. Only one of these industries appears in Figure 5, which showed that management served as the modal non-coal industry for about 4 percent of coal workers born between 1955 and 1985. Comparing the point estimates in Panel B of Table 6 to the sample means shows that coal shock exposure is associated with very large relative declines in the number of years employed in other high-wage industries, whether or not this is in the same CZ or a different CZ. The point estimates in column 3 (-1.098) and column 6 (-0.252) each represent about a 160 percent decline over the associated sample means, suggesting that exposed coal workers are extremely unlikely to transition to these

[30] 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.

[31] 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 is utilities. Conducting this analysis with utilities as the only high-wage, non-mining sector yields similar conclusions to that in 6.

Table 6: Exposure to coal shock and earnings and employment 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							
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.431***	0.860***	-1.407***	-0.478***	0.059*	-0.345***	-0.120***
	(0.087)	(0.109)	(0.099)	(0.085)	(0.029)	(0.025)	(0.016)
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							
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.321***	1.313***	-1.098***	-0.313***	0.115***	-0.252***	-0.086***
	(0.035)	(0.101)	(0.085)	(0.082)	(0.024)	(0.016)	(0.014)
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							
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-0.157***	-0.123***	-0.245***	-0.237***	-0.129***	-0.310***	-0.210***
	(0.010)	(0.012)	(0.047)	(0.016)	(0.015)	(0.029)	(0.012)
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<0.01, ** p<0.05, * p<0.1

other high-wage industries. Coal workers are more likely to transition into relatively low-wage industries. This could be due to the fact that coal workers' skills do not necessarily translate into the demands of these other high-wage industries, or because job opportunities in these high-wage industries are relatively scarce in the labor markets in which coal workers reside. Still, exposed coal workers who do spend time employed in these high-wage industries in other labor markets experience relatively large declines in earnings per year employed. This is consistent with recent evidence showing that coal offers uniquely high wages, even compared to other high-wage industries. Card et al. (2023) show that coal mining offers *the* highest industry wage premium, after accounting for worker and employer-level heterogeneity.

Our final decomposition exercise considers potential heterogeneity in earnings and employment trajectories based on the extent to which industry depends on local demand. We define industries as tradable, non-tradable, construction, or other. The definition of these categories follows 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.[32] Mining activities are defined as a tradable industry. 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 coal workers do not appear to be differentially more mobile than non-coal workers, their earnings and employment trajectories in non-mining industries may be dictated to some degree by these local spillovers.

Table 7 reports this decomposition exercise. Noting that coal mining is classified as a tradable industry, the point estimates in column 2 are consistent with the evidence presented in the earlier decomposition exercises. Cumulative earnings and employment losses for exposed coal workers are offset by employment within the tradable industry category.[33] The largest contribution to reductions in cumulative earnings and employ-

[32]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).

[33]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 7: Exposure to coal shock and earnings and employment by sector, 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									
$\mathbf{1}[Coal_{i,2007\text{-}11}]$	-1.431***	1.161***	0.041	-0.326***	-1.902***	-0.052	0.003***	-0.091***	-0.265***
	(0.087)	(0.164)	(0.027)	(0.047)	(0.129)	(0.031)	(0.003)	(0.016)	(0.026)
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									
$\mathbf{1}[Coal_{i,2007\text{-}11}]$	-0.321***	1.864***	0.031	-0.297***	-1.696***	0.085**	-0.001	-0.079***	-0.229***
	(0.035)	(0.140)	(0.025)	(0.043)	(0.127)	(0.028)	(0.003)	(0.013)	(0.020)
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									
$\mathbf{1}[Coal_{i,2007\text{-}11}]$	-0.157***	-0.143***	-0.293***	-0.232***	-0.295***	-0.189***	-0.241***	-0.237***	-0.287***
	(0.010)	(0.008)	(0.029)	(0.015)	(0.025)	(0.019)	(0.037)	(0.027)	(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<0.01, ** p<0.05, * p<0.1

ment comes from employment in the "other" category. The point estimate in column 5 of Panel B indicates that exposed coal workers spend 1.7 fewer years employed in "other" industries within their initial CZ than observationally similar workers. Panel C 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 columns 2 and 3 of Panel C indicates that the reduction in earnings per year employed is about twice as large for years

industries).

employed in “non-tradable” industries compared to years employed in “tradable” industries. 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.

4.3 Alternative sources of income

At the same time that exposed workers experience earnings and employment declines during the recent coal shock, the composition of workers' total incomes may shift such that other sources supplement lost wage earnings. A large body of literature has documented, for example, that declining labor market opportunities often catalyze an increase in 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 observe the receipt of SSDI specifically, we do observe whether the individual receives any Social Security benefits, defined as having received a form SSA-1099 information return. 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 have not yet reached the full retirement age; most workers will be below the minimum age for drawing Social Security retirement benefits (62). 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.

Columns 1 and 2 of Table 8 report the point estimates of β_1 in equation 2, where the outcome variable is defined as the number of years the worker receives a SSA-1099 over the 2012–2019 period. The sample in column 2 is restricted to workers born in 1960 or later. The point estimate in column 1 suggests that workers most exposed to the recent

Table 8: Exposure to coal shock and receipt of SSA/self-employment income, 2012-2019

	(1)	(2)	(3)	(4)
	# of years SSA-1099 >0		# of years self-emp. (1040) >0	
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	0.297***	0.167***	-0.132***	-0.133***
	(0.030)	(0.018)	(0.029)	(0.027)
Outcome mean (SD)	0.30 (1.12)	0.14 (0.79)	0.74 (1.71)	0.75 (1.69)
Controls	✓	✓	✓	✓
Region FE	✓	✓	✓	✓
Sample	all	born 1960-	all	born 1960-
Observations	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 number of years between 2012 and 2019 in which the worker filed any self-employment (1040) income. In even-numbered columns (2 and 4), 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<0.01, ** p<0.05, * p<0.1

coal shock report 0.3 additional years of SSA-1099 receipt over the 8-year outcome period compared to observationally similar workers. When limited to the slightly younger cohort of exposed coal workers, the magnitude of the effect declines to 0.17 additional years. Comparing these point estimates to the outcome means reveals that these effects are quite large. Among the slightly younger cohort, coal shock exposure is associated with an increase in the number of years that workers receive Social Security benefits that is over 100% greater than the sample mean between 2012 and 2019. Given that these individuals are not yet eligible for early retirement, this is almost certainly driven by SSDI receipt. These findings suggest that coal workers may be able to recoup some of their earnings losses, but arguably through a "second-best" transfer mechanism. This implies that there may be fiscal benefits if lower cost interventions to help smooth the transitional costs of the decline of coal can be identified. Hyman et al. (2024) evaluate the effects of wage insurance provisions, which support workers for whom re-training is ineffective, infeasible, or unavailable. In the context of the U.S. Trade Adjustment Assistance Act, they show these provisions are associated with increases in short-run employment probabilities and higher cumulative earnings in the long run.

In the final two columns of Table 8, we explore how coal shock exposure influences the receipt of self-employment (as reported on Schedule SE of form 1040) income. The point estimates suggest that workers most exposed to the coal shock report 0.13 fewer years of self-employment over the 2012–2019 period compared to observationally similar workers — a decline of about 17 percent of the outcome mean. This could be a reflection of the relative skills of exposed coal workers, which may translate poorly to various forms of self-employment, or of the labor markets in which coal is concentrated, which may be less amenable to successful entrepreneurial 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 novel setting to explore how exposed workers are affected by the shifting labor market opportunities associated with a changing energy landscape. By leveraging rich administrative data on the universe of coal workers between 2005 and 2019, we provide systematic and comprehensive evidence on the consequences of, and responses to, the decline of coal by individual workers in the United States.

On average, we estimate that between 2012 and 2019, workers most exposed to the coal shock experienced a decline in cumulative earnings that exceeded an entire year's worth of earnings, worked about one-third of a year less (a reduction of about 4 percent relative to the sample mean), and earned about 16 percent less per year compared to observationally similar workers. Non-employment is the primary activity for the plurality of individuals in years in which workers are separated from coal.

Decomposing these aggregate effects across firms, industries, and geographies, we show that reallocating across industries and labor markets does not attenuate the adverse consequences of the shock. Aggregate losses are driven by years in which exposed coal workers are not engaged in mining and extraction activities, which includes years of non-employment. We find evidence that exposed coal workers are only marginally less geographically mobile than observationally similar workers, and that exposed coal workers spend fewer years employed in non-mining industries both inside and outside of their initial labor markets. In relative terms, this extensive margin reponse is quite similar across labor markets, and relocation does not attenuate the effect of exposure on earnings per year employed. Whether workers remain in the same labor market or relocate, they earn approximately 30 percent less per year employed when working outside of mining and extraction activities compared to observationally similar workers who switch industries. This suggests that geographic barriers are unlikely to be the sole factor influencing workers' earnings losses. Decomposing effects across industries according to the industry wage, we find that exposed coal workers are relatively unlikely to spend time employed in comparably high-paying industries, and they receive lower earnings per year in these high-paying industries than observationally similar workers, which suggests that coal workers' skills may not translate to those demanded by other high-wage industries. In addition, we estimate that reductions in earnings per year employed in industries relatively more dependent on local demand are similar whether or not these years are observed inside or outside of the initial CZ, indicating that reductions in local demand arising from the coal shock are not a first-order driver in explaining the intensive margin of earnings losses. Finally, we note that exposed coal workers may recoup some of the documented earnings losses via 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 exposed workers. The clean energy transition is poised to reduce demand for fossil fuels, as well as energy-intensive industries, both of which have historically provided high wages in 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 the smooth adjustment to the energy transition. While both skill and geographic mismatch may be playing important roles in influencing workers' earnings and employment trajectories, we find relatively limited evidence suggesting that geographic mobility would substantially reduce the transitional costs to coal workers. Understanding the extent to which barriers to re-skilling can be remediated in practice will be important in determining the welfare consequences of the clean energy transition for workers in legacy sectors.

References

Acemoglu, Daron, David Autor, David Dorn, Gordon H. Hanson, and Brendan Price, "Import Competition and the Great US Employment Sag of the 2000s," *Journal of Labor Economics*, January 2016, *34* (S1), S141–S198.

Adão, Rodrigo, Costas Arkolakis, and Federico Esposito, "Spatial Linkages, Global Shocks, and Local Labor Markets: Theory and Evidence," *NBER*, 2019, pp. 1–66.

Aragón, Fernando M and Juan Pablo Rud, "Natural Resources and Local Communities: Evidence from a Peruvian Gold Mine," *American Economic Journal: Economic Policy*, May 2013, *5* (2), 1–25.

Autor, David, David Dorn, and Gordon Hanson, "On the Persistence of the China Shock," *Brookings Papers on Economic Activity*, 2021, p. 96.

Autor, David H, David Dorn, and Gordon H Hanson, "The China Syndrome: Local Labor Market Effects of Import Competition in the United States," *American Economic Review*, October 2013, *103* (6), 2121–2168.

Autor, David H., David Dorn, Gordon H. Hanson, and Jae Song, "Trade Adjustment: Worker-Level Evidence," *The Quarterly Journal of Economics*, November 2014, *129* (4), 1799–1860.

Autor, David H, Frank Levy, and Richard J Murnane, "The Skill Content of Recent Technological Change: An Empirical Exploration," *Quarterly Journal of Economics*, 2003, *118*, 1279–1333.

Bartik, Timothy J., *Who benefits from state and local economic development policies?*, Kalamazoo, Mich: W.E. Upjohn Institute for Employment Research, 1991.

Black, Dan A., Kermit Daniel, and Seth G. Sanders, "The Impact of Economic Conditions on Participation in Disability Programs: Evidence from the Coal Boom and Bust," *American Economic Review*, February 2002, *92* (1), 27–50.

_, Terra G. McKinnish, and Seth G. Sanders, "Does the availability of high-wage jobs for low-skilled men affect welfare expenditures? Evidence from shocks to the steel and coal industries," *Journal of Public Economics*, September 2003, *87* (9-10), 1921–1942.

_ , _ , and _ , "The Economic Impact of the Coal Boom and Bust," *The Economic Journal*, 2005, *115* (503), 449–476. Publisher: [Royal Economic Society, Wiley].

Blanchard, Olivier Jean and Lawrence F. Katz, "Regional Evolutions," *Brookings Papers on Economic Activity*, 1992, *1992* (1), 1–75. Publisher: Brookings Institution Press.

Blonz, Joshua, Brigitte Roth Tran, and Erin Troland, "The Canary in the Coal Decline: Appalachian Household Finance and the Transition from Fossil Fuels," *NBER*, 2023.

Borusyak, Kirill, Rafael Dix-Carneiro, and Brian K. Kovak, "Understanding Migration Responses to Local Shocks," *Working Paper*, 2022.

Card, David, Jesse Rothstein, and Moises Yi, "Industry Wage Differentials: A Firm-Based Approach," *NBER*, 2023.

Carley, Sanya, Tom P. Evans, and David M. Konisky, "Adaptation, culture, and the energy transition in American coal country," *Energy Research & Social Science*, March 2018, *37*, 133–139.

Charles, Kerwin Kofi, Yiming Li, and Melvin Stephens, "Disability Benefit Take-Up and Local Labor Market Conditions," *The Review of Economics and Statistics*, July 2018, *100* (3), 416–423.

Coglianese, John, Todd D. Gerarden, and James H. Stock, "The Effects of Fuel Prices, Environmental Regulations, and Other Factors on U.S. Coal Production, 2008-2016," *The Energy Journal*, January 2020, *41* (1).

Colmer, Jonathan, Eva Lyubich, John Voorheis, and Kyle Addison, "Nice Work if You Can Get It? The Distribution of Employment and Earnings during the Early Years of the Clean Energy Transition," 2022.

Davis, Rebecca J., J. Scott Holladay, and Charles Sims, "Coal-Fired Power Plant Retirements in the United States," *Environmental and Energy Policy and the Economy*, January 2022, *3*, 4–36.

Davis, Steven J. and Till von Wachter, "Recessions and the Costs of Job Loss," *Brookings Papers on Economic Activity*, 2011, *2011* (2).

Goldsmith-Pinkham, Paul, Isaac Sorkin, and Henry Swift, "Bartik Instruments: What, When, Why, and How," *American Economic Review*, August 2020, *110* (8), 2586–2624.

Greenstone, Michael, "The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures," *Journal of Political Economy*, December 2002, *110* (6), 1175–1219.

Hakkala, Katariina Nilsson and Kristiina Huttunen, "Worker-Level Consequences of Import Shocks," *Institute for the Study of Labor (IZA)*, 2016, *Discussion Paper No. 10033.*

Hanson, Gordon H, "Local Labor Market Impacts of the Energy Transition: Prospects and Policies," in "Economic Policy in a More Uncertain World," Washington, DC: The Aspen Institute, 2022, pp. 155–199.

Humphries, Marc, "The U.S. Coal Industry: Historical Trends and Recent Developments," *Congressional Research Service*, 2017, *R44922.*

Hyman, B., B. Kovak, and A. Leive, "Wage Insurance for Displaced Workers," *Working Paper*, 2024.

Jacobsen, Grant D. and Dominic P. Parker, "The Economic Aftermath of Resource Booms: Evidence from Boomtowns in the American West," *The Economic Journal*, 2016, *126* (593), 1092–1128.

Jacobson, Louis S., Robert J. LaLonde, and Daniel G. Sullivan, "Earnings Losses of Displaced Workers," *The American Economic Review*, 1993, *83* (4), 685–709. Publisher: American Economic Association.

Keller, Wolfgang and Hale Utar, "International trade and job polarization: Evidence at the worker level," *Journal of International Economics*, November 2023, *145*, 103810.

Kolstad, Charles D., "What Is Killing the US Coal Industry?," Technical Report, Stanford Institute for Economic Policy Research 2017.

Krause, Eleanor, "Job loss, selective migration, and the accumulation of disadvantage: Evidence from Appalachia's coal country," *Working Paper*, 2023.

Lachowska, Marta, Alexandre Mas, and Stephen A. Woodbury, "Sources of Displaced Workers' Long-Term Earnings Losses," *American Economic Review*, October 2020, *110* (10), 3231–3266.

Linn, Joshua and Kristen McCormack, "The roles of energy markets and environmental regulation in reducing coal-fired plant profits and electricity sector emissions," *The RAND Journal of Economics*, 2019, *50* (4), 733–767.

Mian, Atif and Amir Sufi, "What Explains the 2007–2009 Drop in Employment?," *Econometrica*, 2014, *82* (6), 2197–2223.

Moretti, Enrico, "Local Labor Markets," in "Handbook of Labor Economics," Vol. 4, Elsevier, 2011, pp. 1237–1313.

Morris, Adele C, Noah Kaufman, and Siddhi Doshi, "The risk of fiscal collapse in coal-reliant communities," *Columbia University SIPA and The Brookings Institution*, 2019, pp. 1–56.

Neal, Derek, "Industry-Specific Human Capital: Evidence from Displaced Workers," *Journal of Labor Economics*, 1995, *13* (4), 653–677. Publisher: [University of Chicago Press, Society of Labor Economists, NORC at the University of Chicago].

Notowidigdo, Matthew J, "The Incidence of Local Labor Demand Shocks," *Journal of Labor Economics*, 2020, *38* (3), 687–725.

Partridge, Mark D., Michael R. Betz, and Linda Lobao, "Natural Resource Curse and Poverty in Appalachian America," *American Journal of Agricultural Economics*, 2013, *95* (2), 449–456. Publisher: [Agricultural & Applied Economics Association, Oxford University Press].

Pierce, Justin R. and Peter K. Schott, "The Surprisingly Swift Decline of US Manufacturing Employment," *American Economic Review*, July 2016, *106* (7), 1632–1662.

Redding, Stephen J, "Trade and Geography," in "Handbook of International Economics," Vol. Chapter 3, Amsterdam: Elsevier-North Holland, 2022, pp. 147–217.

Schmieder, Johannes F., Till Von Wachter, and Jörg Heining, "The Costs of Job Displacement over the Business Cycle and Its Sources: Evidence from Germany," *American Economic Review*, May 2023, *113* (5), 1208–1254.

Topel, Robert, "Specific capital and unemployment: Measuring the costs and consequences of job loss," *Carnegie-Rochester Conference Series on Public Policy*, September 1990, *33*, 181–214.

Voorheis, John, Jonathan Colmer, Kendall A. Houghton, Eva Lyubich, Mary Munro, Cameron Scalera, and Jennifer R Withrow, "Building the Prototype Census Environmental Impacts Frame," *NBER*, 2023.

Walker, W. Reed, "Environmental Regulation and Labor Reallocation: Evidence from the Clean Air Act," *American Economic Review*, May 2011, *101* (3), 442–447.

_ , "The Transitional Costs of Sectoral Reallocation: Evidence From the Clean Air Act and the Workforce*," *The Quarterly Journal of Economics*, November 2013, *128* (4), 1787–1835.

Yagan, Danny, "Employment Hysteresis from the Great Recession," *Journal of Political Economy*, 2019, *127* (5), 2505–2558.

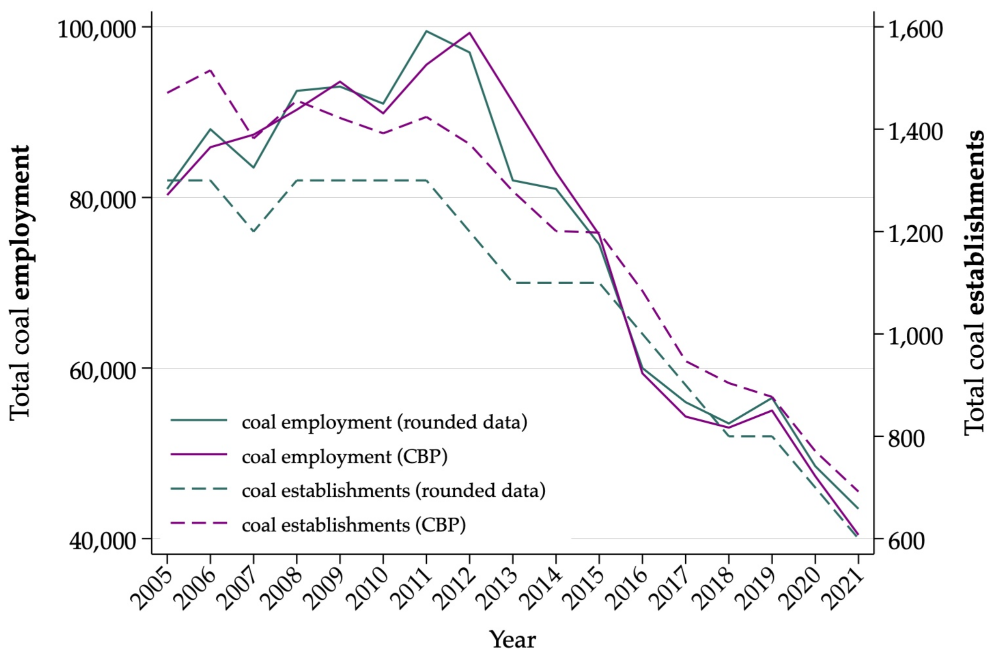
Òscar Jordà, "Estimation and Inference of Impulse Responses by Local Projections," *American Economic Review*, February 2005, *95* (1), 161–182.

_ , "Local Projections for Applied Economics," *Federal Reserve Bank of San Francisco, Working Paper Series*, July 2023, *2023* (16), 01–35.

Appendix

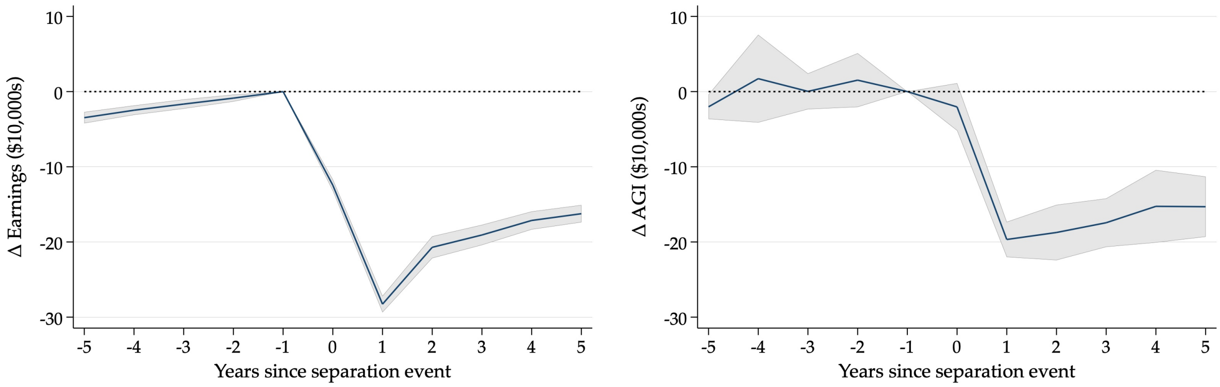
A Appendix Figures

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: Separations from coal and the evolution of earnings and income



(a) W-2 Earnings

(b) Adjusted Gross Income

Note: This figure plots the bivariate relationship between a firm separation and the evolution of earnings and income 5 years on either side of the separation event. The event is defined as the year of separation. Separations may include switches into non-employment. The sample is limited to workers born between 1955 and 1985 with non-negative AGI. Each estimate is the result of a separate bivariate regression estimated for each time horizon, based on a modified version of equation 1 that includes controls for 2005-level age group and gender dummies as well as year and Census region fixed effects. Panel A) presents the association between a separation event and W-2 earnings. Panel B) presents the association between a separation event and adjusted gross income. 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.

B Margins of adjustment: Alternative specifications

B.1 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 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 reflects 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.

[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).

Table B1: 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	(4) # of years in 2011 CZ
$\mathbb{1}[Coal_{i,2007\text{-}11}]$	-1.031***	-0.210***	-0.114***	0.070
	(0.079)	(0.034)	(0.009)	(0.044)
Controls	✓	✓	✓	✓
Spatial proximity control (ϕ_{ij})	✓	✓	✓	✓
Region FE	✓	✓	✓	✓
Observations	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. All regressions include the full set of worker-level controls from equation 2, as well as the control for spatial linkages defined in 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<0.01, ** p<0.05, * p<0.1

Table B1 reports the coefficient estimates β_1 from equation 2 with the inclusion of this control for the CZ's spatial proximity 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 28 and 37 percent smaller than the central estimates with the inclusion of this control. This indicates that controlling for the indirect effects of shocks in related labor markets indeed dampens the direct effects of the individual-level shock exposure Adão et al. (2019). The magnitude of the coefficient on the number of years spent living in the same CZ is about 64 percent smaller and no longer statistically significant. That this migration-related response is quantitatively influenced by the inclusion of this control is consistent with Borusyak et al. (2022), who demonstrates that shocks facing potential alternative labor markets locations will influence an individual's migration decisions.

While smaller in magnitude, the conclusions drawn from this exercise are similar to those drawn from the primary specification. The primary specification can be thought of as revealing the direct 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 this direct effect of individual-level exposure, confirming that the economic conditions in related labor markets also influence an individual's earnings and employment trajectory. 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 7. If anything, controlling for spatial proximity to other coal shocks exacerbates the differences across columns in these exercises. For example, the difference between cumulative earnings and employment declines garnered in the same CZ and different industry versus a different CZ and different industry are *larger* when controlling for spatial linkages. This likely reflects the fact that communities with greater spatial proximity to the coal shock have relatively fewer alternative employment opportunities outside of the industry that offer comparable wages.

B.2 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 an individual works for the coal mining industry as his or her 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.2.1 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 can be thought of as representing the effect of an additional year of attachment to the coal industry in the years preceding the coal shock, rather than reflecting the effect of a dichotomous definition of exposure. 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

Table B2: 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	(4) # of years in 2011 CZ
# Years in coal, 2007–2011	-0.487***	-0.099***	-0.054***	0.060***
	(0.029)	(0.009)	(0.003)	(0.010)
Controls	✓	✓	✓	✓
Region FE	✓	✓	✓	✓
Observations	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 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<0.01, ** p<0.05, * p<0.1

are reported in Table B2. 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 about 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 5.4 percent per year relative to the 2007–2011 annual wage. Again, exposed coal workers spend more years living in their 2011 CZ than less exposed workers. The qualitative conclusions are largely similar to those drawn from the primary analysis. Exposure to the coal shock, defined based on a worker's tenure in the industry, yields relatively large earnings and employment losses between 2012 and 2019, when the coal shock was in full force.

B.2.2 Binned treatment variable

The results in Section B.2.1 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 B3, 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 B3 confirm that workers with greater exposure to the coal shock, in terms of tenure in the industry between 2007 and 2011, is associated with larger cumulative earnings and employment losses than workers with partial exposure to the shock. Individuals who worked in the coal industry for 4-5 years from 2007 and 2011 lost about 2.3 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 one 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 — number of years worked between 2012 and 2019 — is over three times as large for the most

[3]One could bin the continuous variable according into many different groups. The conclusions are insensitive to this choice.

Table B3: 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	(4) # of years in 2011 CZ
1-3 years in coal, 2007–2011	-1.006***	-0.175***	-0.114***	0.215***
	(0.117)	(0.026)	(0.014)	(0.057)
4-5 years in coal, 2007–2011	-2.345***	-0.472***	-0.262***	0.328***
	(0.153)	(0.044)	(0.017)	(0.051)
Controls	✓	✓	✓	✓
Region FE	✓	✓	✓	✓
Observations	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 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.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

exposed workers relative to partially exposed workers. The effect on the intensive margin — earnings per year employed — is about 2.3 times as large for the most exposed workers. Scaling the coefficient estimates in columns 1-3 from Table B2 by the number of years in each bin reveals that these estimates are roughly consistent with relatively linear impacts of exposure on outcomes.[4] This linearity is less apparent in terms of geographic mobility. Compared to observationally similar individuals who worked zero years in coal between 2007 and 2011, the most exposed coal workers spend about 17 more weeks in their 2011 CZ between 2012 and 2019, while those with partial exposure spend about 11 more weeks in their 2011 CZ. Comparing the magnitude of the coefficients in Table B3 to those in Table 2 confirms that the inclusion of "partially exposed" coal workers in the

[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.

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.