Structural Change and Economic Dynamics xxx (xxxx) xxx

Contents lists available at ScienceDirect

Structural Change and Economic Dynamics

journal homepage: www.elsevier.com/locate/strueco

Energy transitions and labor market patterns in the U.S. coal industry

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ARTICLE INFO

Article history:
Received 16 December 2021
Revised 13 July 2022
Accepted 14 July 2022
Available online xxx

JEL Codes:
I38
J21
J31
Q43
O13
R11

Keywords:
Labor market dynamics

ABSTRACT

The U.S. coal industry is in the midst of a transition. Changes in regulation and technological innovation from other fossils and renewables have affected its competitiveness. These could have significant impacts on the labor market where jobs could be lost. In this study, we investigate how changes in employment in the coal industry affect wages in 20 industries in 10 U.S. coal producing states. We assess how these transitions impact welfare programs, since coal producing regions are associated with higher poverty levels. Results show that in the long run, migration of coal workers decreased wages in the construction, manufacturing sectors. Point estimates reveal that an increase in separations of coal workers increase Supplemental Nutrition Assistance Program (SNAP) caseloads. In states where coal mining has a smaller contribution to GDP, an increase in coal employment increases SNAP caseloads.

1. Introduction

The current energy transition experienced by the U.S. is rapidly transforming the economic fabric of several regions across the country (Carley et al., 2018; Crowe and Li, 2020). Coal accounted for 19.5 % of installed capacity in 2020 down from 42 % in 1990 (U.S. Energy Information Administration, 2021a). This rapid transition has not been painless for coal-producing regions which have experienced social change in quality of life and labor productivity (Haerer and Pratson, 2015). This geographical unbalance, explained by the distribution of coal resources has several consequences for economic development (Haerer and Pratson, 2015, Lee and Yang, 2019). The transition in the coal industry has been driven by five factors: (1) advanced mechanization (Tabuchi, 2017); (2) declining mining productivity and higher costs associated with mining deeper subsurface coal (U.S. EIA, 2013; Tierney, 2016); (3) availability of cheaper natural gas, making it a favorable substitute for electric power generation (which has seen increased input from renewables heightened by government incentives to promote renewable energy from wind and solar) (Haerer and Pratson, 2015) (U.S. EIA, 2020; Database of State Incentives for Renewables & Efficiency, 2021); (4) environmental regulation governing powerplant emissions[1] and (5) relatively higher costs of Appalachian metallurgical coal which hurts its competitiveness with coal from other US regions (Kearney, 2016).

Previous works have looked at how other energy technologies may absorb part of the coal industry, including transportation and coal-power generation. However, the regionalization of these job losses, combined with the interaction among the coal mining sector and failure to be re-employed, has not yet been explored. The effects of job losses in the coal industry on social welfare programs have also not been studied. To fill this gap, this work seeks to answer three research questions: (1) *How does migration from the coal industry to industry i affect wages in industry i?* (2) *How do former (unemployed) coal workers affect welfare programs?* and (3) *Do changes in coal related wages affect welfare caseloads?* An overview of the objectives of this study are illustrated in Fig. 1. Answering these three questions is important in the context of emerging discourses around the proposed Green New Deal, and its objective to initiate a transition towards low-carbon energy production in the

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[1] Though a study estimated that recent environmental regulations only accounted for about 3.5 percent of the total 33 percent decline in U.S coal production. Houser et al. (2017). "Can coal make a comeback?" New York, NY: Columbia Center on Global Energy Policy.

https://doi.org/10.1016/j.strueco.2022.07.005

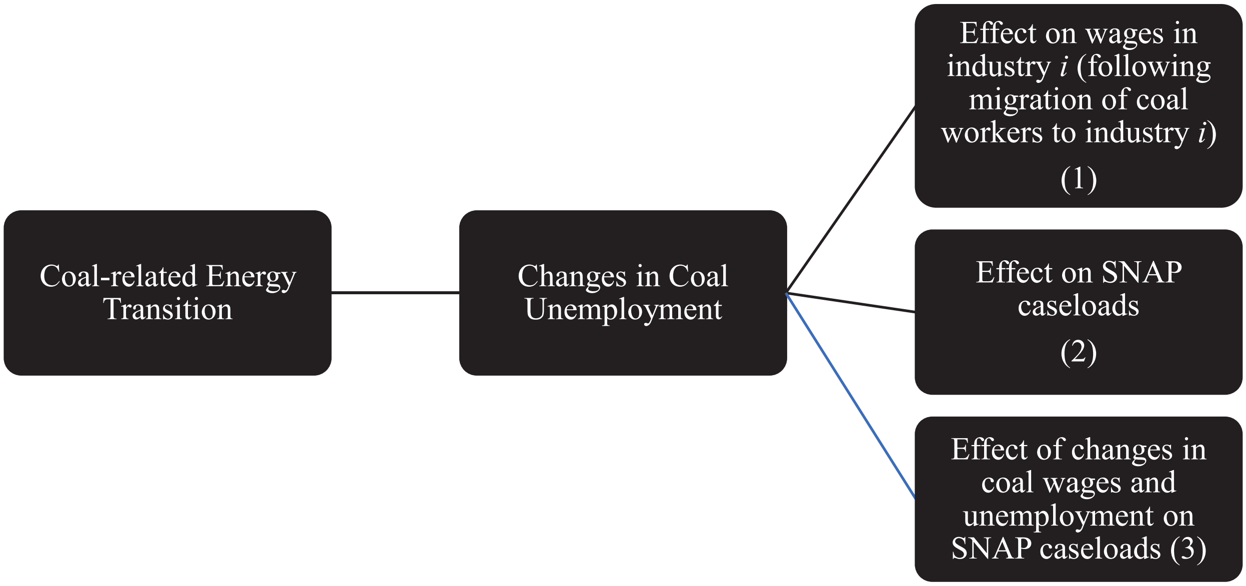

Fig. 1. Overview of the Study
Note: Numbers 1 – 3 represent the objectives of the study

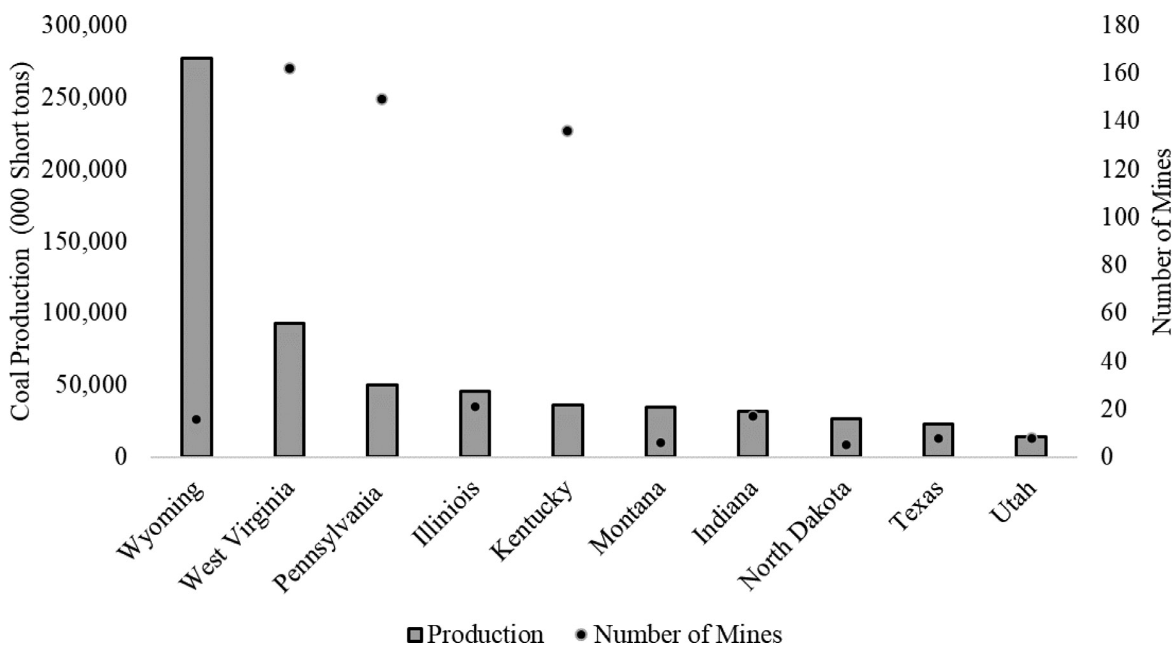

Fig. 2. Coal Production and Number of Mines by State (2019)
Source: Author's Adaptation from the U.S. Energy Information Administration (2021a).

U.S. with an element of social justice embedded into it (Galvin and Healy, 2020).

As a highly regional industry, coal mining is concentrated in a few states across the U.S.. Wyoming is the largest producer of coal followed by West Virginia, Pennsylvania, Illinois and Kentucky. In 2019, the five states produced half a billion tons of coal with Wyoming contributing 276.9 million tons. West Virginia, Pennsylvania, Illinois and Kentucky produced 93.3, 50.1, 45.9 and 36 million tons, respectively (U.S. Energy Information Administration, 2021a). Interestingly, West Virginia had the largest number of coal mines at 162, followed by Pennsylvania (149), Kentucky (136) and Illinois (21). Wyoming had 16 mines while the others had less than 10 as illustrated in Fig. 2 below.

This paper contributes to the literature in several ways. It is the first study to assess the effects that inter-sectoral migrations of workers from the coal mining sector exercise on 20 other sectors in the 10 largest coal producing states in the U.S.. Second, it looks at the relationship between the number of unemployed former coal workers and how they impact welfare programs – a topic which has not been assessed in the literature. Third, the analysis uses a rich dataset from the U.S. Census Bureau (2021) which focusses on coal workers at a granular level. These data track coal workers who migrated from the coal sector to other sectors (e.g. manufacturing, construction), and coal workers who separated from the coal industry but did not find employment. The dataset also includes wages for current coal workers at the state level. Fourth, our empirical strategy employs quarterly data which capture monthly and seasonal dynamics that may not be captured using annual data. Fifth, we employ time series models which present findings in both the long- and short-run for the panel (panel ARDL) dataset. At the state level, a non-linear autoregressive distributed lag (NARDL) model is employed to examine the asymmetric effects of coal wages and employment on Supplemental Nutrition Assistance Program (SNAP) caseloads. This approach enables tests for causality in both the long- and short-run in an asymmetric fashion. The advantage of using asymmetric relationships relates to the fact that the response of SNAP participation to a change in wages will differ, based on whether salaries increase or decrease. This rich set of findings will assist with policy formulation. By understanding the interactions between welfare policies, and inter-intra sectoral job market dynamics, we can identify areas of friction and opportunities between regional development and the low-carbon transition process, developing coherent, just and effective regional strategies rooted in place-based approaches (Bartik, 2020). The approach we use in this work also builds upon existing transition literature by measuring how much and identifying 'to where' employment in the coal industry has migrated as a consequence of several forms of shocks, changes in prices, and macro-shocks such as the 2008 Global recession. It also seeks to assess the spillover effects to the economy (wages, employment, SNAP program participation) following changes in the coal industry.

Our results suggest that, in the long run, migration of coal workers decreased wages in the construction, manufacturing, wholesale, utilities, professional, transport and administration sectors. Short-run findings indicate that an increase in coal wages leads to a rise in wages in construction, manufacturing, wholesale, retail trade, real estate, professional and accommodation sectors. Estimates also show that an increase in coal separations increased SNAP participation in the long-run, while short-run estimates imply that higher coal earnings reduce SNAP uptake. Findings from the employment – welfare relationship indicate that in states where mining, quarrying, and oil and gas extraction have a lesser contribution to GDP, increasing coal employment increases SNAP caseloads. We also find that higher natural gas prices cause SNAP caseloads to increase in most states in our sample, while a decrease in prices reduces caseloads. Point estimates indicate that when wages in other sectors are higher than those in the coal sector, there are pull effects, and employment in the coal sector declines, particularly in manufacturing and construction, suggesting the existence of strong pipelines among these two sectors.

The rest of the paper is organized as follows. The next section reviews literature while Section 3 presents an overview of coal production in the U.S.. Section 4 discusses the data and empirical strategies used in the study. Section 5 contains summary statements and concludes the study.

2. Literature review

Over the past decade, the rapid decline in employment and revenue experienced by the coal mining sector in the U.S. has driven research aimed at understanding the social and economic effects of energy transitions (Carley et al., 2018). As low carbon energy sources become increasingly competitive, one of the greatest risks to successful transformation is the process of 'un-locking' from high carbon industry clusters with powerful influence over political processes and great ability to generate inertia (Fouquet, 2016). This inertia may be arguably justified if large numbers of regionally-concentrated workers become long term unemployed as a result of the low carbon transition. The search for specific drivers of decline leads us to identify two themes within literature. The first seeks to identify the drivers of the coal sector decline in the U.S. and to quantify the effects of the transition away from coal mining in producing regions, often analyzing the value-chain wide effects. The second stream of literature seeks to understand the attitudes of people in declining producing regions towards clean energy technologies and their drivers/barriers (Table 1). In both cases, literature has investigated the effects across multiple US and international regions, at varying scales, and often grouping fossil fuels or mining industries together. In two instances, we identified works that address research questions relevant to both streams (Table 1).

Within the first stream of literature, open trade, good governance, competition, and well-regulated labor markets have been found to facilitate the flow of resources from declining high-carbon sectors to growing and more productive low-carbon activities (Zenghelis et al., 2018). For instance, Kotchen et al. (2017) found that the public strongly supports using carbon tax revenue to aid workers in high carbon industries. Thus, it is paramount that policies related to low carbon transitions seek to minimize the risks of stranded labor. In this specific stream of literature, authors have chosen regional perspectives to highlight the transitions. The work by Haerer and Pratson (2015) presented a comprehensive, nationwide analysis of employment trends in the U.S. between 2008 and 2012, and found that the coal industry lost employment in the post-crisis period, a trend that has accelerated since then. At the local level, Jolley et al. (2019) showed that the employment effects of transitioning away from coal production are substantial since mining activities often generate 2.0 to 3.0 additional jobs.

The economic impacts of coal mining vary depending on time and place. Black et al. (2005) found that during the coal boom of the 1970s, coal mining's contribution to the local economies were fairly modest where one mining job created 0.174 local sector jobs, and each mining job lost (during the bust) destroyed 0.349 local sector jobs. This dynamic also explains the limited demographic expansion of coal-producing regions during periods of production expansion. In recent years, the focus of this first stream of literature has been directed on the 'bust' cycles of coal. Betz et al. (2015) showed that communities within the Appalachian region of the U.S. with higher coal employment shares drive out population and dampen entrepreneurship activities. These counties (Appalachian counties with greater coal employment) experienced lower income levels at the close of the 1990s, though the 2000s, along with higher energy prices and a recession (Lobao et al., 2016). Coal was also found to drive economic growth in the broader Eastern U.S. region, while negative patterns of growth were shown to exist in regions west of the Mississippi (Deller, 2014). Several authors have taken holistic approaches to assess the economic impacts of coal mining and/or the overall coal value chain, analyzing the regional effects of the long-term decline in employment, and ultimately in output/demand of the coal sector. For example, Jolley et al. (2019) used an IMPLAN model to estimate the effects of decommissioning coal-fired power plants in Ohio and found that 1,100 jobs would be lost together with \$8.5 million in tax revenue. Blaacker, et al. (2012) found that in West Virginia, the overall impact of coal mining closures would be smaller than expected due to the mechanization of the extraction process. Jordan et al. (2018) noted that of the 1,699 coal mines closed closures in the Appalachian region between 2002 and 2016, 1287 mines closed for non-profit-related reasons, including the depletion of reserves, regulatory compliance, or physical damage to the mine. Although there were around 110 coal mine openings per year between 2002 and 2010, far fewer opened afterwards, when coal prices fell. They concluded that rising production costs explain two-thirds of the coal mines that closed due to declining profits between 2002 and 2012, natural gas prices and reduced electricity consumption independently explain one-third of the closures.

Within the second stream of literature, Haggerty et al. (2018) and Roemer and Haggerty (2021) pointed to the lack of coordination among different levels of governments for the large magnitude of negative socioeconomic impacts which stemmed from coal mining closures. This strand of literature presents a highly regionalized set of results which suggest that coal mining operations are deeply affected by the surrounding

Table 1
Summary of relevant literature by stream related to coal transitions.

Source	Stream	Focus
Zenghelis et al. (2018)	Drivers and effects of decline	United Kingdom
Haerer and Pratson (2015)	Drivers and effects of decline	USA
Jolley et al. (2019)	Drivers and effects of decline	Ohio (USA)
Black (2005)	Drivers and effects of decline	USA (selected states)
Betz et al. (2015)	Drivers and effects of decline	Appalachian Region (USA)
Lobao et al. (2016)	Drivers and effects of decline	Appalachian Region (USA)
Deller (2014)	Drivers and effects of decline	USA
Jordan et al. (2018)	Drivers and effects of decline	USA
Blaacker et al. (2012)	Mixed	West Virginia (USA)
Kotchen et al. (2017)	Mixed	USA
Carley et al. (2018)	Attitudes and Transition	Appalachian Region (USA)
Haggerty et al. (2018)	Attitudes and Transition	Western USA
Roemer and Haggerty (2021)	Attitudes and Transition	Western USA
Pai et al. (2021)	Attitudes and Transition	India, China, USA, Australia
Louie and Pearce (2016)	Attitudes and Transition	USA
Pollin and Callaci	Attitudes and Transition	USA
Crowe and Li (2020)	Attitudes and Transition	USA (selected states)
Cha (2020)	Attitudes and Transition	Wyoming (USA)
Herrera et al. (2017)	Attitudes and Transition	USA
Karaki (2018)	Attitudes and Transition	USA
Karaki and Herrera (2015)	Attitudes and Transition	USA

socio-ecosystem. Scholars have also investigated the ability of other energy sectors to absorb the workforce from the coal mining sector. Most recently, Pai et al. (2020) identified the solar energy sector as one that holds more promise than the wind energy sector in absorbing coal miners. Furthermore, the geography of the U.S. coal mining sector offers the opportunity to exploit wind and solar energy sources locally, thus addressing spatial issues related to out- and in-migration of the workforce, and ameliorating spatial-justice issues that may have emerged with previous frameworks (Louie and Pearce, 2016; Pollin and Callaci, 2019).

The communities affected by this decline in historic coal-mining regions like Appalachia are conscious of the problematic future coal has and are eager to embrace new opportunities from renewable energy technologies (Carley et al., 2018). Similar attitudes were found in other macro-regions of the U.S. such as Texas in the South, and Vermont in New England (Crowe and Li, 2020), though acceptance towards a new job market landscape is not always unopposed, as found by Cha (2020) in the case of Wyoming.

Overall, the qualitative literature helps us to build a framework for interpreting the dynamics of job flows from the coal mining sector to other industries. However, we still need a better understanding of the drivers leading to workers choosing certain sectors, as well as the ability of other industries to attract and retain former coal mining workers. Scholars working on energy transitions have investigated this perspective before: specifically, the oil and gas mining industry has been analyzed to provide a better understanding of which sectors jobs migrate to, and the linkages between oil and gas extractive industries to manufacturing and service industries (Herrera et al., 2017). Expectedly, responses to these shocks are not equal across producing regions (Karaki, 2018), because they rely on aggregate channels (Herrera and Karaki, 2015).

3. Overview of coal production in the US

3.1. Coal production in the US

The total number of employees in the coal industry in the U.S. declined by 75 % over 35 years, from 172,800 workers in 1985 to 42,500 in 2020 (Bureau of Labor Statistics, 2018). Over the same period, coal production dropped by 20 %, from 883.6 to 706.3 million short tons, as illustrated in Fig. 3 (U.S. Energy Information Administration, 2021a).

At the same time coal's closest alternative, natural gas, has seen its price drop significantly from an average of $7 between 2003 and 2008, to $3.94 in 2009. Between 2009 and 2020, the average price of natural gas dropped further to $3.36 (U.S. Energy Information Administration, 2021a). Hydraulically fractured horizontal wells became the major method of new natural gas development in October 2011, and in 2016 the wells accounted for 69 % of all oil and natural gas wells drilled in the United States (Cook et al., 2018). These patterns have significant effects on the coal industry, since natural gas has become a cheaper alternative for electricity production (Mao et al., 2005).

3.2. Coal establishments and employment

The number of establishments in the coal mining industry has declined over the past two decades as illustrated in Fig. 4. Between 2001 and 2010, Kentucky had the largest number of establishments (366), followed by West Virginia, Pennsylvania and Virginia. Today, West Virginia has the most establishments (183) while Mississippi has the least (4). Pennsylvania, Ohio, Virginia and Alabama each have 162, 63, 61, and 50 establishments, respectively (U.S. Energy Information Administration, 2021a). The largest drop in coal establishments over the last 20 years took place in the Appalachian region as shown in Fig. 5.

An analysis of the sectoral patterns of coal employment in the period 2001 to 2019, shows that coal mining workers have migrated to other energy sectors, oil, and, to a lesser extent, the construction industry (Fig. 6). The pattern of these inter-sectoral migrations is not surprising because of the overlap in skills needed across mining-related sectors (Heath, 2000).

The largest change in coal employment over the last two decades took place in the Appalachian region, with Tennessee witnessing the largest drop in numbers. Surprisingly, coal employment increased in Wyoming and Mississippi during this period as indicated in Fig. 7.

3.3. The SNAP program

The Supplemental Nutritional Analysis Program (SNAP) provides food assistance to 42 million low-income Americans every month (USDA, 2022a). Its goal is to supplement the food budget of needy families so they can purchase healthy food (Mabli et al., 2013; USDA, 2022b). For individuals or households to receive benefits, certain income and resource requirements must be met at the state and federal level.

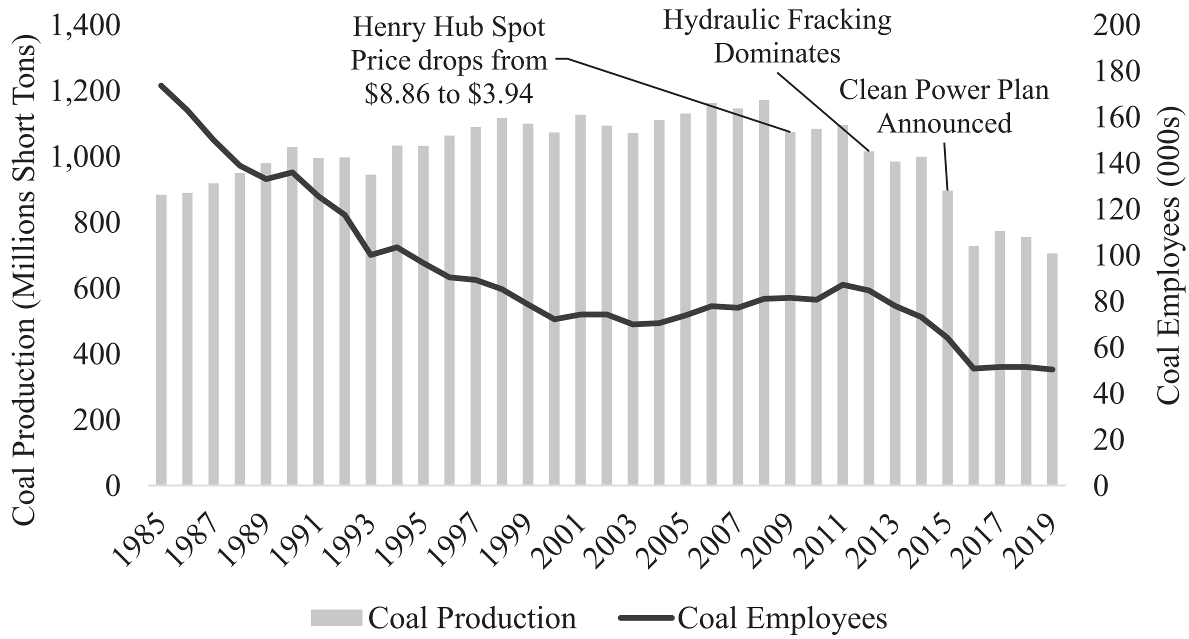

Fig. 3. Coal Production and Employment in the U.S.
Source: Authors Adaptation from the U.S. Energy Information Administration (2021a) and Bureau of Labor Statistics (2018).

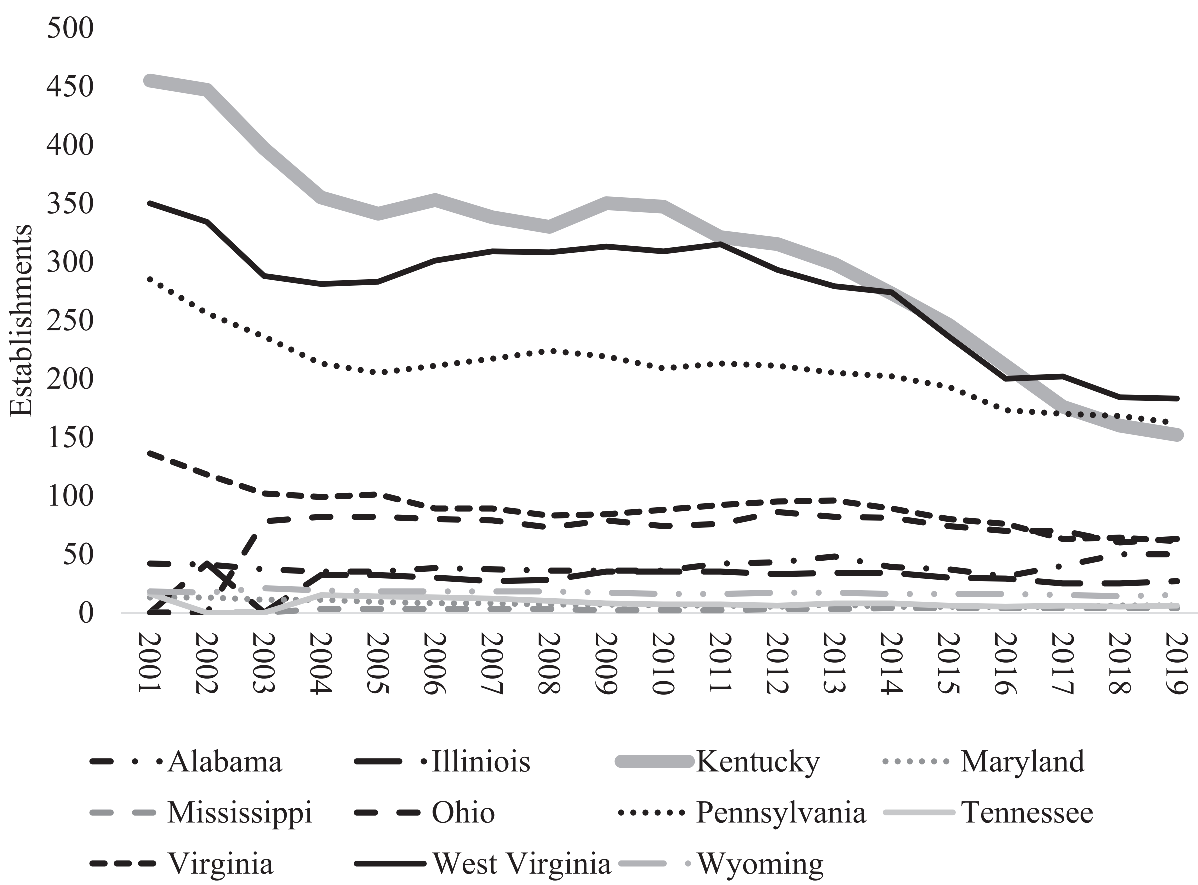

Fig. 4. Number of Establishments (Coal Mining
Source: Adapted from the Bureau of Labor Statistics (2021).

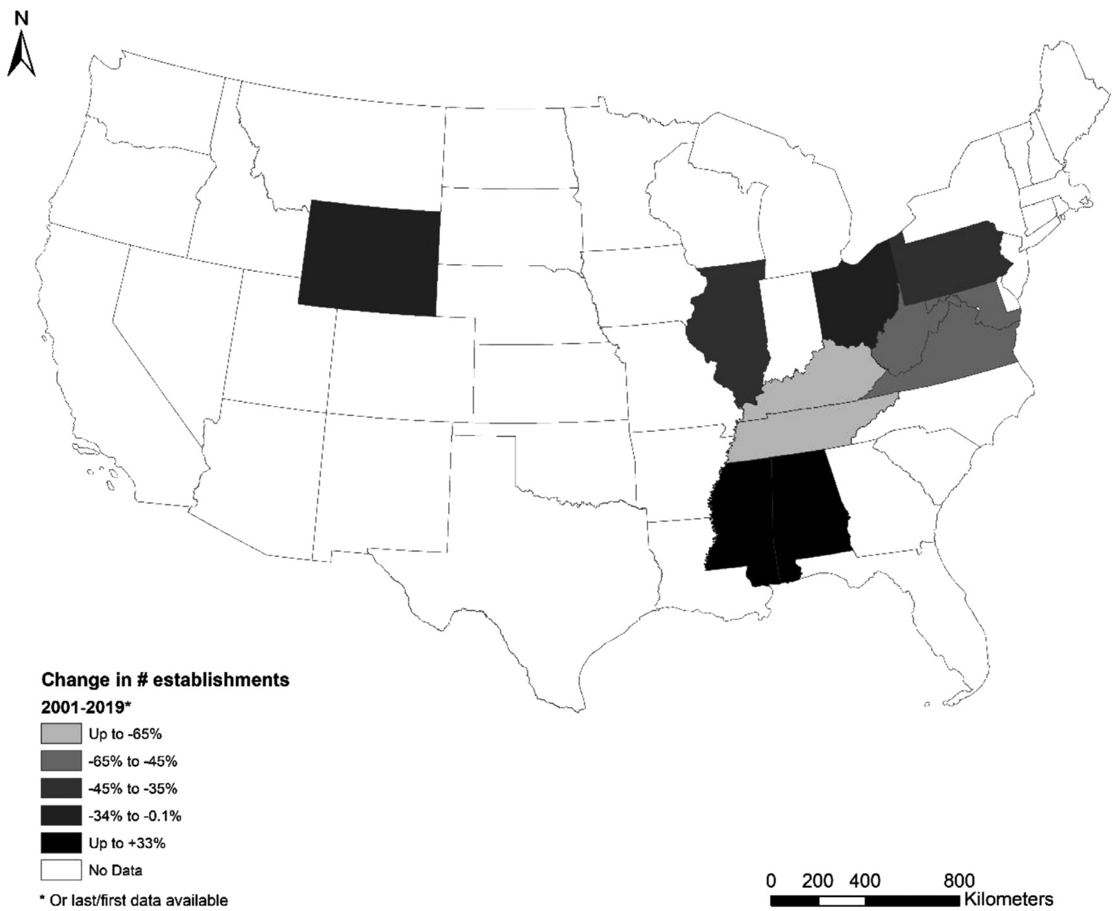

Fig. 5. Change in the number of coal establishments 2001–2019.

Studies have shown that in some sectors such as construction, job quality has deteriorated to a level where wages are too low, causing workers to rely on U.S. safety net programs such as the SNAP program (Jacobs et al., 2022). In the energy sector, Higdon and Robertson (2020) showed how the shift away from fossil fuels has caused economic downturns, ultimately increasing the number of families and individuals partaking in the SNAP programs. The connection between labor market dynamics in the coal industry and SNAP uptake can be tracked at the monthly level, making the SNAP program a good proxy for understanding the connection between labor market conditions and welfare programs.

4. Data and methods

4.1. Data

The data used in this study are summarized in Table 2 and were collected at the state level for all quarters between 2001 and 2018. The study focuses on the top 10 coal producing states in the U.S. which include: Alabama, Illinois, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and Wyoming (U.S. Energy Information Administration, 2021a). Sectoral data were collected from the Quarterly Census of Employment and Wages (QCEW) at the Bureau of Labor Statistics (2021), based on the North American Industrial Classification System (NAICS) 4 and 2 digits partitions[2].

[2] The U.S. Census Bureau (2021) provides the job-to-job migration data at the 3-digit subsectors and 4-digit industries.

Our empirical strategy first assesses how wages in each of the NAICS-2 digit sectors (henceforth NAICS sectors) were affected by the migration of coal workers to other sectors. We then turn our attention to the effects of wages on welfare policies.

4.2. Coal worker migration and wages

In the first scenario, we assess how wages in the construction industry are affected by the number of workers migrating from the coal to construction industry. Other factors affecting wages in the construction industry include construction employment, coal employment, coal wages, the price of natural gas, and the state's personal income (a measure of economic conditions). This exercise is conducted for 19 other NAICS sectors: Agriculture, Forestry, Fishing and Hunting; Mining, Quarrying, and Oil and Gas Extraction; Utilities; Manufacturing; Wholesale Trade; Retail Trade; Transportation and Warehousing; Information; Finance and Insurance; Real Estate and Rental and Leasing; Professional, Scientific, and Technical Services; Management of Companies and Enterprises; Administrative and Support and Waste Management and Remediation Services; Educational Services; Health Care and Social Assistance; Arts, Entertainment, and Recreation; Accommodation and Food Services; Other Services (except Public Administration); Public Administration.

The pooled mean group (PMG) approach in the panel ARDL model is employed for this empirical analysis since it allows for short-run heterogeneity in conjunction with long-run homogeneity of the variables in the model (Pesaran et al., 1999). The panel

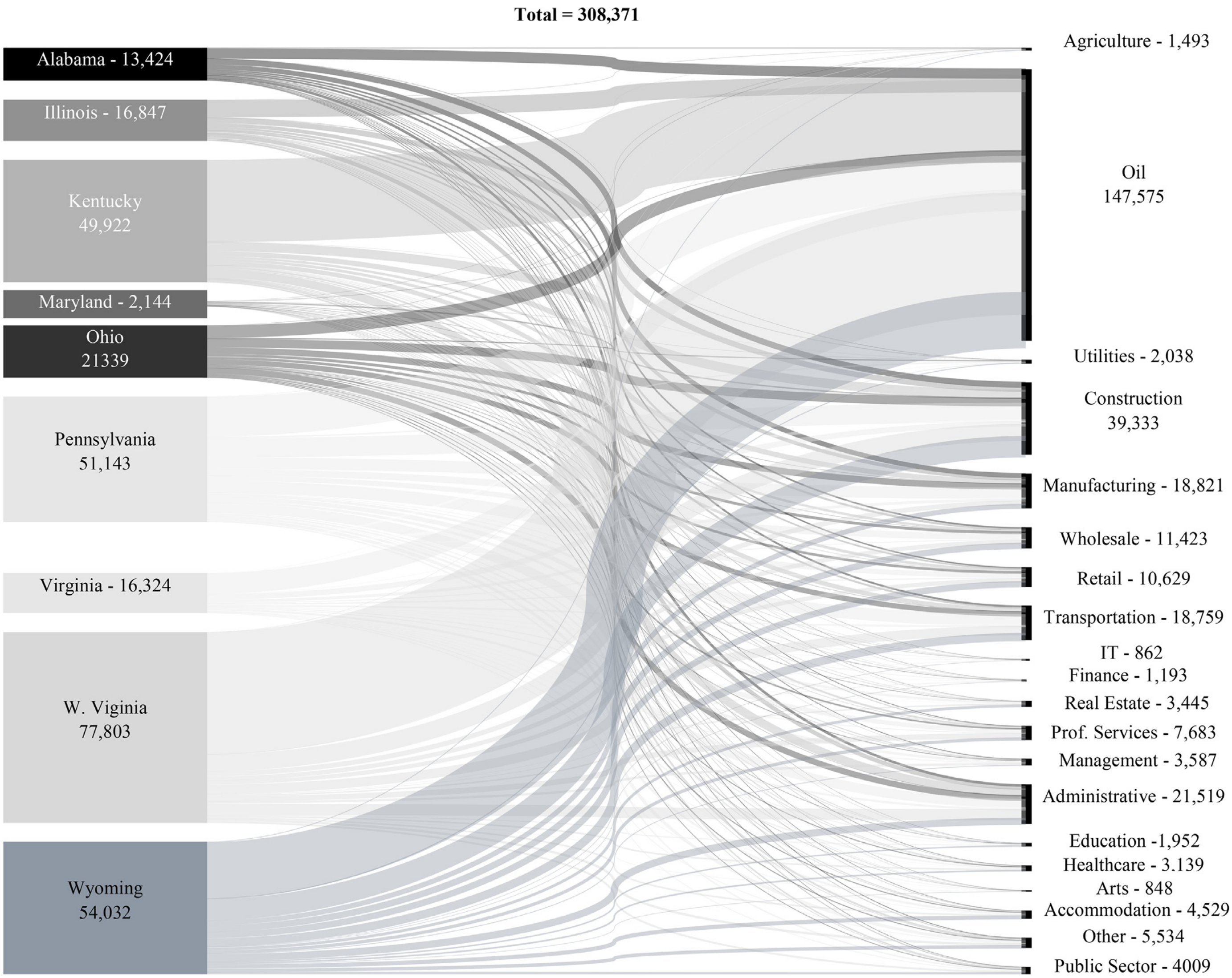

Fig. 6. Patterns of intra-sectoral migration of coal mining workers across 10 U.S. states between 2001 and 2018
Source: Author's Adaptation from the Longitudinal Employer Household Dynamics (LEHD). U.S. Census Bureau (2021).

Table 2
Variables and data sources.

Variable Label	Indicator Name	Source
Coal_employment	Coal Employment (End of Quarter Employment: Counts)	U.S. Census Bureau (2021) NAICS 4-digit Industries (2121 Coal Mining)
Employment by Sector	Employment by Sector (End of Quarter Employment: Counts)	U.S. Census Bureau (2021) (NAICS Sectors)
Coal_wages	Coal Mining Wages (Average Monthly Earnings)	U.S. Census Bureau (2021) NAICS 4-digit Industries (2121 Coal Mining)
Henry_hub	Natural Gas Spot Price, Monthly Henry Hub Value ($/MMBTU)	U.S. Energy Information Administration (2021)
Fmr_coal	Job to Job Flows from the coal industry to other sectors.	Quarterly Workforce Indicators (QWI) produced by the Longitudinal Employer Household Dynamics (LEHD). U.S. Census Bureau (2021)
SEP	The number of coal workers whose job with their employer ended in the specified quarter.	Quarterly Workforce Indicators (QWI) produced by the Longitudinal Employer Household Dynamics (LEHD). U.S. Census Bureau (2021)
EARNSEPS	The average monthly earnings of coal workers who lost their jobs from employers	Quarterly Workforce Indicators (QWI) produced by the Longitudinal Employer Household Dynamics (LEHD). U.S. Census Bureau (2021)
Wages by Sector	Average Weekly Wages	Quarterly Census of Employment and Wages (QCEW) at the Bureau of Labor Statistics (2021)
Income	Personal income (millions of dollars, seasonally adjusted)	U.S. BEA (2021)
RPS	U.S. Renewables Portfolio Standards: 2019 Annual Status Update	Galen (2019)
SNAP_HH	SNAP Participation (Households)	USDA FNS (2021)
SNAP_Persons	SNAP Participation (Persons)	USDA FNS (2021)

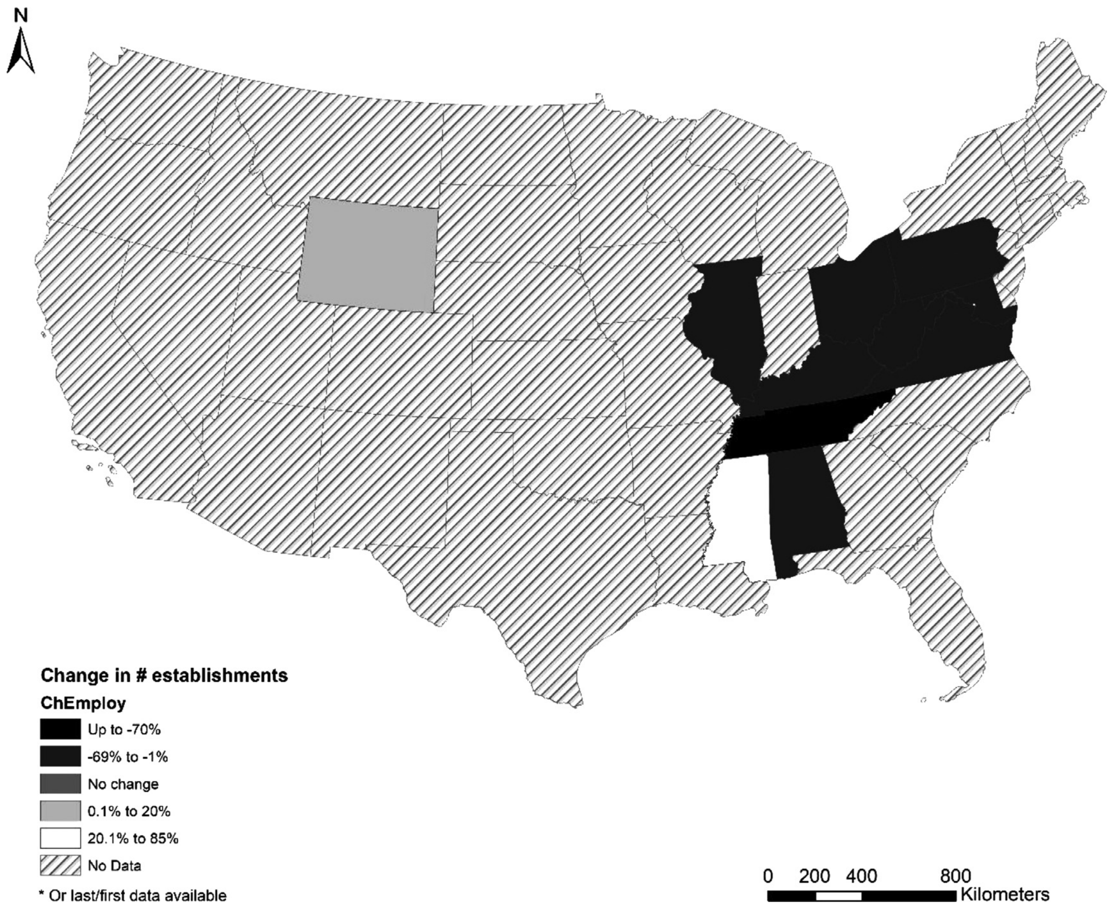

Fig. 7. Change in coal employment, 2001–2019.

ARDL $(p, q, q \cdots q)$ model is specified as follows.

$$\mathrm{wages}_{\mathrm{it}} = \mu_{\mathrm{i}} + \sum_{j=1}^{p} \tau_{\mathrm{ij}} \mathrm{wages}_{\mathrm{i,t-j}} + \sum_{j=0}^{q} \delta_{\mathrm{ij}}' \mathrm{X}_{\mathrm{i,\ t-j}} + \mathrm{u}_{\mathrm{it}} \quad (1)$$

Where: *wages* are wages by sector; $\mathrm{i} = 1 \cdots \mathrm{N}$ are the cross-section units (10 states); $t = 1 \cdots T$ are time periods (2001 : Q1 to 2018 : Q4); X the vector of explanatory variables *employment_sector_i*, *coal_to_sector_i*, *coal_employment*, *coal_wages*, *henry_hub*, *personal_income*, and a variable to capture the 2008 Recession. Pesaran et al. (1999) argue that it is more convenient to work with the following parameterization of (1).

$$\Delta \mathrm{wages}_{\mathrm{it}} = \mu_{\mathrm{i}} + \varphi_{\mathrm{i}} \left(\mathrm{wages}_{\mathrm{i,t-1}} - \beta_{\mathrm{i}}' \mathrm{X}_{\mathrm{it}} \right) + \sum_{j=1}^{p-1} \tau_{\mathrm{ij}}^{**} \Delta \mathrm{wages}_{\mathrm{i,t-j}} + \sum_{j=0}^{q-1} \delta_{\mathrm{ij}}^{*\prime} \Delta \mathrm{X}_{\mathrm{i,t-j}} + \mathrm{u}_{\mathrm{it}} \quad (2)$$

Where β_i are our vector of interest which measure the long run impact of the independent variables on wages, u_{it} is an error term which is independently distributed across i and t, and φ_i the error correction term. The remaining parameters are the short run coefficients. The model was estimated for the panel of 10 states using 18 years of quarterly data. Eq. (2) is estimated using the PMG estimator developed by Pesaran et al. (1999). Long and short run results are presented in Tables 3 and 4, respectively.

5. Results

5.1. Long run results

We focus on whether migration of workers from the coal industry to other sectors affects the sectors' wages. Table 3 presents the long run impacts on wages of industry *i*, following migration of workers from the coal industry. Point estimates indicate that in the long run, migration of coal workers to the construction industry decreased construction wages. Similar findings were observed in the manufacturing, wholesale, utilities, professional, transport and administration sectors. Interestingly, wages in the management sector increased following an influx of workers from the coal sector. We surmise that the coal workers joining the management sector have a higher skill-set and human capital investment than the average worker in the sector and drive wages up. Results also show that wages in the agriculture, oil, retail, information, health, arts and accommodation sectors were not influenced by coal migration patterns.

Our estimates also indicate that a rise in coal wages Granger causes an increase in wages in most sectors (12 of the 20 industries) of the economy. Coal wages, however, have no impact on wages in the administration, health, arts and accommodation industries. Further, wages in the education sector increased following an increase in coal employment. This finding suggests that an increase in coal workers leads to a rise in tax revenue, which could increase wage and salary earnings for teachers –

Table 3
Impacts on Wages of Industry *i*, Following Migration of Workers from the Coal Industry: PMG Estimation – *Long Run Results*: Panel ARDL(1,1,1,1,1,1,1)

	$Wages_{i=agriculture}$	$Wages_{i=oil}$	$Wages_{i=utilities}$	$Wages_{i=construction}$	$Wages_{i=manufacturing}$
Employment_sector_i	-0.0047***	0.0090***	-0.0125**	8.36E-06	0.0001
[p-value]	[0.0000]	[0.0000]	[0.0366]	[0.9499]	[0.2113]
Coal_to_sector_i	-0.3998	-0.0332	-5.7578***	-0.3173***	-0.3925*
[p-value]	[0.7188]	[0.3425]	[0.0074]	[0.0000]	[0.0942]
Coal_Employment	-0.0103***	-0.0133***	-0.0206***	0.0027	-0.0138***
[p-value]	[0.0000]	[0.0000]	[0.0000]	[0.3870]	[0.0000]
Coal_Wages	0.0019	0.1837***	0.1449***	-0.0074	0.0885***
[p-value]	[0.5675]	[0.0000]	[0.0000]	[0.2282]	[0.0000]
Henry_Hub	-0.8358	-1.6699	-8.2861**	-2.1787*	2.8527**
[p-value]	[0.2318]	[0.3330]	[0.0107]	[0.0738]	[0.0454]
Personal_Income	0.0010***	0.0003***	0.0011***	0.0015***	0.0008***
[p-value]	[0.0000]	[0.0072]	[0.0000]	[0.0000]	[0.0000]
	$Wages_{i=wholesale}$	$Wages_{i=retail}$	$Wages_{i=transport}$	$Wages_{i=information}$	$Wages_{i=finance}$
Employment_sector_i	-0.0007	0.0010***	0.0011***	0.0001	0.0031***
[p-value]	[0.4201]	[0.0000]	[0.0000]	[0.8554]	[0.0021]
Coal_to_sector_i	-1.3294***	0.3739	-0.6125***	2.7586	3.1250
[p-value]	[0.0084]	[0.1206]	[0.0003]	[0.2435]	[0.3448]
Coal_Employment	-0.0136***	-0.0030***	-0.0074***	-0.0133***	-0.0161***
[p-value]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Coal_Wages	0.0509***	0.0289***	0.0306***	0.0630***	0.1354***
[p-value]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Henry_Hub	4.7232**	-1.3811**	-1.3493	-0.7853	-1.0496
[p-value]	[0.0327]	[0.0424]	[0.2341]	[0.6423]	[0.7316]
Personal_Income	0.0018	0.0006***	0.0008***	0.0014***	0.0014***
[p-value]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
	$Wages_{i=real\ estate}$	$Wages_{i=professional}$	$Wages_{i=management}$	$Wages_{i=administrative}$	$Wages_{i=education}$
Employment_sector_i	0.0064***	0.0019***	-0.0021*	-0.0008***	-0.0143***
[p-value]	[0.0000]	[0.0000]	[0.0763]	[0.0000]	[0.0000]
Coal_to_sector_i	0.7515	-2.4515***	5.7692***	-1.3077***	0.7802
[p-value]	[0.4791]	[0.0000]	[0.0034]	[0.0052]	[0.6673]
Coal_Employment	-0.0054***	-0.0108***	-0.0158***	0.0131***	0.0410***
[p-value]	[0.0006]	[0.0000]	[0.0002]	[0.0012]	[0.0000]
Coal_Wages	0.0710***	0.0577***	0.1713***	-0.0030	-0.0133
[p-value]	[0.0006]	[0.0000]	[0.0000]	[0.4920]	[0.3527]
Henry_Hub	-4.2039*	-1.0812	12.4415**	-2.8919***	-6.8880**
[p-value]	[0.0531]	[0.6029]	[0.0129]	[0.0013]	[0.0182]
Personal_Income	0.0012***	0.0016***	0.0026***	0.0019***	0.0049***
[p-value]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
	$Wages_{i=health}$	$Wages_{i=arts}$	$Wages_{i=accomodation}$	$Wages_{i=other}$	$Wages_{i=public}$
Employment_sector_i	0.0008***	-0.0035***	0.0005***	0.0009***	0.0064***
[p-value]	[0.0000]	[0.0000]	[0.0000]	[0.0001]	[0.0000]
Coal_to_sector_i	-0.5110	-0.0964	-0.3210	-1.0803*	3.7023***
[p-value]	[0.4931]	[0.9346]	[0.2311]	[0.0915]	[0.0008]
Coal_Employment	-0.0021	0.0009	0.0027*	-0.0080***	-0.0085***
[p-value]	[0.6089]	[0.3361]	[0.0724]	[0.0000]	[0.0000]
Coal_Wages	0.0038	0.0016	0.0016***	0.0028	0.1328***
[p-value]	[0.5432]	[0.4855]	[0.4147]	[0.4334]	[0.0000]
Henry_Hub	0.6641	-0.3173	-1.4305***	-1.6748*	6.6510***
[p-value]	[0.5876]	[0.5821]	[0.0001]	[0.0692]	[0.0031]
Personal_Income	0.0005***	0.0010***	0.0003***	0.0010***	0.0016***
[p-value]	[0.0001]	[0.0000]	[0.0000]	[0.0000]	[0.0000]

*Denotes significance at 10%, **Denotes significance at 5%, ***Denotes significance at 1%.

a finding similar to that in Weber (2012). The relationship between changes in natural gas prices and wages is mixed. An increase in the price of natural gas raised wages in manufacturing, wholesale, management and education sectors, while an inverse relationship exists between natural gas prices and wages in the utilities, construction, retail, and accommodation sectors. In this sample, however, natural gas prices did not influence wages in agriculture, oil, transportation, information, finance, professional, health and arts. Finally, as expected, an increase in personal income (or economic conditions) increased wages in all sectors.

5.2. Short run results

In the short run, wages in the construction, manufacturing, retail and transportation industries reduced following an influx of workers from the coal industry (see Table 4). Surprisingly, wages in the education and accommodation sectors went up, following an influx of coal workers. This suggests that coal workers, who are usually paid higher than teachers or food service workers, increase wages in these sectors when hired.

An increase in wages in the coal industry leads to higher wages in the construction, manufacturing, wholesale, retail, real estate, professional and accommodation sectors. This suggests that higher wages in the coal industry increase the purchasing power of residents, driving up demand for consumer goods causing wages for non-coal industries to go up. Another reason for rising wages could be the rise in commuter workers who flock to coal communities during boom periods, increasing demand for hotel accommodation and retail services. Tight labor markets may also drive wages up in the accommodation and food service industry, especially if workers migrate to work in the coal industry during boom periods. Results also showed that higher natural gas prices increased wages in utilities, finance and the professional sectors, while wages in construction declined. Economic conditions do not impact wages in the short run.

Table 4
Impacts on Wages of Industry *i*, Following Migration of Workers from the Coal Industry: PMG Estimation – *Short Run Results*: Panel ARDL(1,1,1,1,1,1,1).

	$Wages_{i=agriculture}$	$Wages_{i=oil}$	$Wages_{i=utilities}$	$Wages_{i=construction}$	$Wages_{i=manufacturing}$
ECT_-1	-0.7004***	-0.5745***	-1.1160***	-0.7502***	-0.4243***
[p-value]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Δ_Employment_sector_i	-0.0287***	-0.0920***	0.0931**	-0.0027**	-0.0019*
[p-value]	[0.0048]	[0.0160]	[0.0221]	[0.0304]	[0.0614]
Δ_Coal_to_sector_i	-1.0906	0.2469	11.0681	-0.7723*	-0.4812**
[p-value]	[0.3373]	[0.2185]	[0.2628]	[0.0679]	[0.0323]
Δ_Coal_Employment	-0.0318	0.1026	-0.1685**	-0.0874	-0.0673
[p-value]	[0.5199]	[0.2179]	[0.0166]	[0.4137]	[0.1117]
Δ_Coal_Wages	0.0098	0.0158	-0.0443	0.0279**	0.0268***
[p-value]	[0.2220]	[0.4762]	[0.4598]	[0.0475]	[0.0002]
Δ_Henry_Hub	-0.3354	0.0724	8.9121*	-2.2345**	1.0869
[p-value]	[0.7754]	[0.9734]	[0.0955]	[0.0387]	[0.1544]
Δ_Personal_Income	0.0022	0.0072**	0.0131	0.0026	0.0034*
[p-value]	[0.1162]	[0.0268]	[0.1037]	[0.3964]	[0.0953]
Recession_2008	1.0536	1.0554	106.7829***	-6.9915	-10.5657***
	[0.7213]	[0.9117]	[0.0000]	[0.2740]	[0.0000]
C	215.4373***	52.7243*	980.9481***	221.5144***	110.4337***
	[0.0000]	[0.0750]	[0.0000]	[0.0000]	[0.0030]
	$Wages_{i=wholesale}$	$Wages_{i=retail}$	$Wages_{i=transport}$	$Wages_{i=information}$	$Wages_{i=finance}$
ECT_-1	-0.4565***	-0.2915***	-0.4203***	-0.7200***	-0.9155***
[p-value]	[0.0000]	[0.0027]	[0.0001]	[0.0000]	[0.0000]
Δ_Employment_sector_i	-0.0223***	0.0008*	-0.0098	-0.0182	-0.0044
[p-value]	[0.0000]	[0.0572]	[0.2739]	[0.3782]	[0.6840]
Δ_Coal_to_sector_i	-0.7026	-0.5727**	-0.5164**	-3.2038	-2.5894
[p-value]	[0.4275]	[0.0176]	[0.0117]	[0.4648]	[0.3071]
Δ_Coal_Employment	-0.1298	-0.0206	-0.0248	-0.0636*	-0.2589
[p-value]	[0.1537]	[0.1438]	[0.5087]	[0.0937]	[0.2200]
Δ_Coal_Wages	0.0337***	0.0062*	0.0096	0.0071	-0.0394
[p-value]	[0.0000]	[0.0515]	[0.2852]	[0.7152]	[0.2476]
Δ_Henry_Hub	-0.2027	-0.0822	2.1257	-4.3591	8.5697***
[p-value]	[0.8207]	[0.8322]	[0.2154]	[0.4769]	[0.0002]
Δ_Personal_Income	0.0032	0.0004	-0.0016	0.0112	0.0045**
[p-value]	[0.1468]	[0.6674]	[0.4356]	[0.3116]	[0.0177]
Recession_2008	-34.1512***	-1.2680	-5.6958	-11.7281	41.7864
	[0.0000]	[0.4698]	[0.1094]	[0.1358]	[0.3512]
C	201.0546***	-23.4486	133.7902***	263.9096***	-323.1086*
	[0.0000]	[0.1377]	[0.0050]	[0.0000]	[0.0750]
	$Wages_{i=real\ estate}$	$Wages_{i=professional}$	$Wages_{i=management}$	$Wages_{i=administrative}$	$Wages_{i=education}$
ECT_-1	-0.3942***	-0.7092***	-0.9037***	-0.3578**	-0.1507**
[p-value]	[0.0000]	[0.0000]	[0.0000]	[0.0144]	[0.0417]
Δ_Employment_sector_i	-0.0458***	-0.0471	0.1128**	-0.0012	0.0003
[p-value]	[0.0027]	[0.1805]	[0.0447]	[0.4713]	[0.3598]
Δ_Coal_to_sector_i	-0.1815	-0.7828	8.1768	0.3036	1.4971***
[p-value]	[0.8450]	[0.6531]	[0.3396]	[0.4521]	[0.0081]
Δ_Coal_Employment	-0.1421	-0.2632*	-0.2712	-0.0151	-0.0167
[p-value]	[0.1253]	[0.0705]	[0.1710]	[0.3987]	[0.4027]
Δ_Coal_Wages	0.0166**	0.0608***	-0.0341	0.0142***	0.0096***
[p-value]	[0.0270]	[0.0008]	[0.5316]	[0.0053]	[0.0047]
Δ_Henry_Hub	1.7217	5.2464**	7.5924	0.8227	-0.4684
[p-value]	[0.3002]	[0.0356]	[0.1434]	[0.1364]	[0.3519]
Δ_Personal_Income	0.0042***	0.0063	0.0164	0.0006	0.0010
[p-value]	[0.0090]	[0.3263]	[0.3618]	[0.6043]	[0.4261]
Recession_2008	-18.3558***	-19.0077**	-7.0453	0.6095	0.1169
	[0.0055]	[0.0214]	[0.6466]	[0.8513]	[0.9845]
C	-79.3951*	73.26866	69.5533	81.1340**	259.6191***
	[0.0647]	[0.3762]	[0.3636]	[0.0268]	[0.0000]
	$Wages_{i=health}$	$Wages_{i=arts}$	$Wages_{i=accomodation}$	$Wages_{i=other}$	$Wages_{i=public}$
ECT_-1	-0.6258***	-0.9695***	-0.4029***	-0.3810***	-0.8060***
[p-value]	[0.0000]	[0.0000]	[0.0000]	[0.0002]	[0.0000]
Δ_Employment_sector_i	0.0018	-0.0032	-0.0003*	-0.0021***	-0.0059***
[p-value]	[0.1489]	[0.2474]	[0.0688]	[0.0011]	[0.0000]
Δ_Coal_to_sector_i	0.0682	0.1431	0.4471***	-0.1995	-1.8515
[p-value]	[0.9289]	[0.9475]	[0.0030]	[0.5607]	[0.3440]
Δ_Coal_Employment	-0.0895	-0.1154	1.56E-05	-0.0188	0.0510
[p-value]	[0.1452]	[0.2650]	[0.9993]	[0.4226]	[0.3988]
Δ_Coal_Wages	0.0323***	0.0226**	0.0046**	0.0216***	-0.0492***
[p-value]	[0.0015]	[0.0222]	[0.0132]	[0.0000]	[0.0000]
Δ_Henry_Hub	0.3179	-1.4593	-0.1438	-1.2547	2.3566
[p-value]	[0.7559]	[0.1402]	[0.7597]	[0.4125]	[0.3689]
Δ_Personal_Income	0.0027	0.0032	-1.52E-05	0.0033	0.0073
[p-value]	[0.4818]	[0.2367]	[0.9557]	[0.3523]	[0.1153]
Recession_2008	-4.6764	2.4381	-0.5714	-1.1884	-2.1796
	[0.1547]	[0.6780]	[0.6521]	[0.5183]	[0.8715]
C	79.81701	325.6963***	11.9318	54.6986**	-382.0100**
	[0.1297]	[0.0000]	[0.4594]	[0.0342]	[0.0174]

* Denotes significance at 10%, ** Denotes significance at 5%, *** Denotes significance at 1%

Table 5
Impacts of Coal Separations on SNAP Participation: PMG Estimation –*Long and Short Run Results*: Panel ARDL(1,1,1,1,1,1) – SNAP.

Long Run Estimates	SNAP_HH	SNAP_Persons
SEP	19.3980**	44.9635**
[p-value]	[0.0221]	[0.0416]
EARNSEPS	-23.3186**	-54.8608**
[p-value]	[0.0397]	[0.0362]
Coal_Wages	52.92995***	137.1240***
[p-value]	[0.0001]	[0.0000]
Personal_Income	-7.28678***	-17.9807***
[p-value]	[0.0000]	[0.0000]
Henry_Hub	-1948.518	-3670.472
[p-value]	[0.2066]	[0.3573]
Short Run Estimates		
ECT_-1	-0.1190***	-0.11095***
[p-value]	[0.0008]	[0.0000]
SEP	-8.9728	-18.2500
[p-value]	[0.5406]	[0.5484]
EARNSEPS	0.8728	1.8756
[p-value]	[0.7334]	[0.7198]
Coal_Wages	-8.59710**	-17.6115**
[p-value]	[0.0346]	[0.0273]
Personal_Income	-0.5946	-1.3345
[p-value]	[0.1402]	[0.1081]
Henry_Hub	1017.061**	2298.705**
[p-value]	[0.0002]	[0.0004]
Recession_2008	3193.969*	9518.385***
[p-value]	[0.0821]	[0.0439]
C	217794.8**	489065.7***
	[0.0122]	[0.0046]
@TREND	2794.963**	5829.718***
	[0.0238]	[0.0065]

* Denotes significance at 10%, ** Denotes significance at 5%, *** Denotes significance at 1%.

5.3. Coal separations and welfare program caseloads

Next, we take a closer look at the workers whose job within the coal industry ended (coal separations or), then assess whether they impacted welfare program caseloads, particularly the Supplemental Nutritional Analysis Program (SNAP). This assessment is tested using the panel ARDL $(p, q, q \cdots q)$ model specified in Eq. (3).

$$\mathrm{SNAP\_HH_{it}} = \mu_i + \sum_{j=1}^{p} \sigma_{ij}\mathrm{SNAP\_HH_{i,t-j}} + \sum_{j=0}^{q} \sigma_{ij}' X_{i,\ t-j} + \varepsilon_{it} \tag{3}$$

Where $i = 1 \cdots N$ are the cross-section units (10 states), $t = 1 \cdots T$ are time periods (2001 : Q1 to 2019 : Q3), X is the vector of explanatory variables *SEP*, *EARNSEPS*, *Coal_Wage*; *Personal_Income*, *Henry_Hub* and a variable to capture the 2008 recession. Pesaran et al. (1999) argue that it is more convenient to work with the following parameterization of (3).

$$\Delta\mathrm{SNAP\_HH_{it}} = \mu_i + \vartheta_i\left(\mathrm{SNAP\_HH_{i,t-1}} - \pi_i' X_{it}\right) + \sum_{j=1}^{p-1} \sigma_{ij}^{**}\Delta\mathrm{SNAP\_HH_{i,t-j}} + \sum_{j=0}^{q-1} \sigma_{ij}^{*\prime}\Delta \mathrm{X_{i,t-j}} + \varepsilon_{it} \tag{4}$$

where π_i is our vector of interest which measures the long run impact of the independent variables on wages, ε_{it} is an error term which is independently distributed across i and t, and ϑ_i the error correction term. The remaining parameters are the short run coefficients. Two specifications are run in this analysis: SNAP household participation (SNAP_HH) and SNAP persons participation (SNAP_Persons). Results are presented in Table 5.

5.4. Long run results

Unsurprisingly, long run findings indicate that an increase in coal separations increases SNAP participation. Also, the lower the wages of workers separating from the coal sector, the higher the SNAP caseloads. Estimates show that increase in earnings for coal workers increases SNAP participation. This finding hints that the resource curse, which was found in the study by Black et al. (2005), exists in coal producing regions. This is because higher coal wages may increase the incentive for students to drop out of school in search for paid opportunities which may create a gap in human capital, and increase the population which is likely to be dependent on SNAP benefits. As expected, an inverse relationship exists between personal income and SNAP participation. Point estimates reveal that the price of natural gas has no effect on SNAP caseloads in the long run.

5.5. Short run results

Short run results indicate that higher coal earnings reduce SNAP caseloads. They also show that the price of natural gas has a positive effect on SNAP caseloads. Based on Knittel et al. (2015), we infer that higher gas prices accelerate transitions away from coal, at least in the short run, which could sway workers away from the coal mines to natural gas projects.

5.6. Coal wages, unemployment, and welfare program caseloads

We then modify the analysis to focus on coal wages and assess their impact on SNAP participation in an asymmetric fashion. The mechanisms through which wages and unemployment affect welfare programs are many, and we assume SNAP participation will be greatly affected. Our analysis disaggregates the panel and we focus on each state within our sample, testing for relationships in the long- and short-run. We employ the recently developed NARDL cointegration methodology which can be employed in small samples and allows for tests of causality when using combinations of I(0) and I(1) series (Bildirici and Turkmen, 2015; Fousekis et al., 2016). The NARDL developed by Shin et al. (2014) is specified in Eq. (5) using data from 2001:Q1 to 2019:Q3.

$$\begin{aligned}\Delta\mathrm{ln\_SNAP\_HH_t} = {} & \alpha_0 + \gamma\,\mathrm{ln\_SNAP\_HH_{t-1}} + \theta_1^+\mathrm{ln\_Coal\_Wage_{t-1}^+} \\ & + \theta_2^-\mathrm{ln\_Coal\_Wage_{t-1}^-} + \theta_3^+\mathrm{ln\_CoalEmp_{t-1}^+} \\ & + \theta_4^-\mathrm{ln\_CoalEmp_{t-1}^-} + \theta_5^+\mathrm{ln\_Pers\_Income_{t-1}^+} \\ & + \theta_6^-\mathrm{ln\_Pers\_Income_{t-1}^-} + \theta_7^+\mathrm{ln\_Henry\_Hub_{t-1}^+} \\ & + \theta_8^-\mathrm{ln\_Henry\_Hub_{t-1}^-} + \sum_{i=0}^{p}\alpha_1\Delta\mathrm{ln\_SNAP\_HH_{t-i}} \\ & + \sum_{i=0}^{q}\alpha_2\Delta\mathrm{ln\_Coal\_Wage_{t-i}^+} + \sum_{i=0}^{q}\alpha_3\Delta\mathrm{ln\_Coal\_Wage_{t-i}^-} \\ & + \sum_{i=0}^{q}\alpha_4\Delta\mathrm{ln\_CoalEmp_{t-i}^+} + \sum_{i=0}^{q}\alpha_5\Delta\mathrm{ln\_CoalEmp_{t-i}^-} \\ & + \sum_{i=0}^{q}\alpha_6\Delta\mathrm{ln\_Pers\_Income_{t-i}^+} \\ & + \sum_{i=0}^{q}\alpha_7\Delta\mathrm{ln\_Pers\_Income_{t-i}^-} + \sum_{i=0}^{q}\alpha_8\Delta\mathrm{ln\_Henry\_Hub_{t-i}^-} \\ & + \sum_{i=0}^{q}\alpha_9\Delta\mathrm{ln\_Henry\_Hub_{t-i}^-} + \varepsilon_t \end{aligned} \tag{5}$$

where *ln_SNAP_HH* represents the log of the number of households participating in the SNAP program; *ln_Coal_Wage* represents the log of the average monthly earnings of employees with stable jobs in the coal industry; *ln_CoalEmp* represents the log of the number of jobs that are held on both the first and last day of the quarter with the same employer in the coal industry; and *ln_Pers_Income* represents the log of personal income in the state and *ln_Henry_Hub* the log of Henry Hub natural gas spot price (dollars per million Btu). The variables are logged for ease of interpretation. The periods p and q denote the optimal lags for the

Table 6
Asymmetric Impacts of Coal Wages on SNAP Participation: NARDL *Long-Run* Results.

Dependent variable: **Δ ln_SNAP_HH**	**Alabama**	**Illinois**	**Kentucky**	**Maryland**	**Ohio**	**Pennsylvania**	**Tennessee**	**Virginia**	**West Virginia**	**Wyoming**
Variable	Coefficient [p-value]	Coefficient [p-value]	Coefficient [p-value]	Coefficient [p-value]	Coefficient [p-value]	Coefficient [p-value]	Coefficient [p-value]	Coefficient [p-value]	Coefficient [p-value]	Coefficient [p-value]
C	3.1504***	2.1867***	1.8582***	1.8430***	3.2453***	3.1689***	1.9470***	3.0240***	3.2542	2.3491***
	[0.0000]	[0.0001]	[0.0002]	[0.0001]	[0.0000]	[0.0000]	[0.0001]	[0.0000]	[0.0000]	[0.0000]
$ln\_SNAP\_HH_{t-1}$	-0.5975***	-0.3964	-0.3563***	-0.3681***	-0.5835***	-0.5699***	-0.3592***	-0.5829***	-0.6593***	-0.5917***
	[0.0000]	[0.0001]	[0.0001]	[0.0001]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]	[0.0000]
$ln\_Coal\_Wage^{+}_{t-1}$	-0.4328*	-0.2728	-0.0624	0.4332**	-0.1518	-0.0747	0.1309	0.1341	0.0314	0.2442
	[0.0568]	[0.1661]	[0.7660]	[0.0155]	[0.3176]	[0.5848]	[0.2044]	[0.2923]	[0.8529]	[0.1496]
$ln\_Coal\_Wage^{-}_{t-1}$	-0.0881	-0.2263	-0.3960	0.4647***	-0.1162	0.0063	0.0443	0.0323	-0.3285	-0.0317
	[0.7087]	[0.3309]	[0.1499]	[0.0074]	[0.5058]	[0.9676]	[0.6150]	[0.8458]	[0.1048]	[0.8493]
$ln\_CoalEmp^{+}_{t-1}$	0.0542	0.5955*	-0.1952	-0.1805**	0.9966**	-0.0316	0.0470	0.4355*	0.1495	0.1072
	[0.5275]	[0.0782]	[0.5281]	[0.0406]	[0.0238]	[0.8444]	[0.4970]	[0.0857]	[0.4477]	[0.5366]
$ln\_CoalEmp^{-}_{t-1}$	0.0702	0.2577	0.3533***	-0.1081	0.1068	-0.0569	0.0393	0.1104	0.2220	-0.7744***
	[0.3340]	[0.1584]	[0.0098]	[0.1522]	[0.2470]	[0.7343]	[0.5195]	[0.3886]	[0.1381]	[0.0011]
$ln\_Pers\_Income^{+}_{t-1}$	1.2636	-0.3122	-0.2640	1.2639	-0.6076	1.4428	0.6594	1.9144**	-0.3054	0.8127**
	[0.1283]	[0.6882]	[0.7851]	[0.2176]	[0.5410]	[0.1509]	[0.5016]	[0.0243]	[0.7233]	[0.0111]
$ln\_Pers\_Income^{-}_{t-1}$	-3.1192**	-0.1064	-0.0868	-5.2413**	1.7691	-0.7709	-0.6134	-0.9762	-0.5826	-0.8819
	[0.0260]	[0.9207]	[0.9488]	[0.0143]	[0.2557]	[0.5973]	[0.7162]	[0.4263]	[0.7282]	[0.1694]
$ln\_Henry\_Hub^{+}_{t-1}$	0.0452	0.0813*	0.1070**	0.0220	0.1497**	0.1163**	0.1931***	0.1710***	0.1339***	0.0566
	[0.4878]	[0.0932]	[0.0480]	[0.7165]	[0.0256]	[0.0192]	[0.0043]	[0.0083]	[0.0018]	[0.3568]
$ln\_Henry\_Hub^{-}_{t-1}$	-0.0433	-0.0654	-0.1144*	-0.1133*	-0.1001	-0.0928	-0.1445**	-0.2239***	-0.1873***	-0.1639***
	[005587]	[0.3139]	[0.0655]	[0.0642]	[0.1134]	[0.1072]	[0.0146]	[0.0001]	[0.0004]	[0.0097]
Recession_2008	-0.0297	0.0130	0.0044	-0.0121	-0.0224	-0.0117	-0.0222	-0.0403***	-0.0147	-0.0445
	[0.1183]	[0.4039]	[0.7795]	[0.4217]	[0.2020]	[0.3793]	[0.1533]	[0.0089]	[0.2485]	[0.0010]

*Denotes significance at 10%, **Denotes significance at 5%, ***Denotes significance at 1%.

dependent and independent variables, respectively, as specified by the Akaike Information Criterion (AIC). α_i denotes short-run coefficients and θ_i denotes long-run coefficients with $i = 1, 2, \cdots, 6$. Lastly, Δ is the first difference operator and ε_t the white noise term. The long-run analysis is used to measure the reaction and speed of adjustment towards equilibrium level while the short-run analysis investigates the immediate impacts of the independent variables' changes on renewable energy (production or consumption). The Wald test is used to test for long-term $(\theta = \theta^{+} = \theta^{-})$ and short-run $(\alpha = \alpha^{+} = \alpha^{-})$ asymmetry. We report findings for the long run asymmetric relationships for in Table 6.

Seven results are worth highlighting[3]. A 10 % increase in wages in the coal industry reduces SNAP participation by 4.3 % in Alabama. In Maryland a positive and negative shock in wages increases SNAP participation by 4.3 and 4.6 %, respectively. Findings from the employment – welfare relationship indicate that in states where mining, quarrying, and oil and gas extraction have a lesser contribution to GDP, increasing coal employment increases SNAP caseloads. In Illinois, Ohio and Virginia, the mining sectors contribute 0.1, one, and 0.2 %, respectively to the states' GDP. A 10 % positive shock in employment in the coal industry increases SNAP participation in Illinois (by 6 %), Ohio (by 10 %) and Virginia (by 4.3 %). Conversely, SNAP caseloads reduced in Maryland following a positive shock in employment. As hypothesized, a 10 % negative shock in employment increased SNAP caseloads by 3.5 % in Kentucky while Wyoming witnessed a 7.7 reduction in caseloads. Intriguingly an increase in personal income was accompanied by an increase in SNAP participation in Virginia and Wyoming while a decrease in income was accompanied by a drop-in caseloads in Alabama and Maryland. The positive income-SNAP caseload relationship in Virginia and Wyoming can be explained by differences in state policies which are beyond the scope of the paper. We leave that investigation to future work.

Point estimates further reveal that a 10-percentage point increase in the price of natural gas was accompanied by an increase in SNAP caseloads in Illinois (0.8 %), Kentucky (1 %), Ohio (1.4 %), Pennsylvania (1.1 %), Tennessee (1.9 %), Virginia (1.7 %) and West Virginia (1.3 %). A 10 % negative shock in gas prices reduced caseloads in Kentucky (1.1 %), Maryland (1.1 %), Tennessee (1.4 %), Virginia (2.2 %), West Virginia (1.9 %) and Wyoming (1.6 %). This infers that higher natural gas prices have the potential to increase unemployment in the coal sector and drive up participation in welfare programs. Studies have suggested that abundance of natural gas and higher prices may harm industries that are not closely related to resource extraction. Labor demand in the extraction industry may be high enough to bid local wages, pulling workers from other lower paying jobs causing the other industries to fail – perhaps the presence of the resource curse (Brown, 2014). In general, results suggest that natural gas prices have a greater influence than coal wages or coal employment on SNAP caseloads, a possible cumulative effect of direct influence on the coal industry and the larger economy. Our results highlight the presence of regional differences across states in the U.S., with no clear-cut differences among macro-regions.

6. Conclusion

Coal is the second largest source of electricity generation in the United States, and is expected to continue to account for a major share over the next several decades (Banks et al., 2015; U.S. EIA 2022). Even though it maintains its historical place as the number one source of fuel for electricity generation, coal has experienced a decline in use. The decline has resulted in loss of jobs and economic hardships in coal producing states.

We investigate the effect of changes in the coal industry on the economy in three objectives. First, we assess whether migrating coal workers have an impact on their new industries' wages. The analysis is conducted on a panel of 10 states and 20 industries using a Panel ARDL model. In the long run, migration of coal workers decreased wages in the construction, manufacturing, wholesale, utilities, professional, transport and administration sectors. In the short run, an increase in the wages in the coal industry led to a rise in wages in construction, manufacturing, wholesale, retail trade, real estate, professional and accommodation sectors.

Second, the relationship between coal separations and welfare programs is investigated in the long and short run using a panel of 10 states, and data between 2001 and 2019. Long run findings indicate that an increase in the separations of coal workers in-

[3] Long run results are reported

creased SNAP participation. Short run findings suggest that higher coal earnings reduce SNAP uptake. Then, we disaggregate the sample and assess the asymmetric relationship between the coal industry and natural gas prices on the SNAP program at the state level. Findings from the employment – welfare relationship indicate that in states where mining, quarrying, and oil and gas extraction have a lesser contribution to GDP, increasing coal employment increases SNAP numbers. Point estimates also reveal that increasing natural gas prices caused SNAP caseloads to increase in most states in our sample, while a decrease in prices reduced caseloads.

Based on these findings, we propose several policies that can best support the communities that have traditionally relied on coal jobs for their livelihoods. First, these regions require targeted efforts aimed at developing human capital with a focus on health, education and the service sector. They can also attract industries offering tradable sector employment, which help the area retain labor, increase wages and reduce poverty. Tradable sectors are immune to local shocks in the economy since their goods are traded internationally. Third, regions ought to develop their transportation systems to community colleges, technical centers and places of new employment so that displaced workers can bridge their skills gaps or find new jobs (Jolley et al., 2019). Policy makers may further support renewable energy development to absorb coal workers and invest in instruction that aids former coal industry workers to transition other jobs (Haerer and Pratson, 2015).

More generally, this paper contributes to the literature on just transitions and highlights the importance of taking account of the welfare of workers in high-carbon industries in the development of the low carbon transition. Employment losses and local decline associated with high carbon-related industries risks acting as a barrier to low carbon transitions – for instance, concern about inequality, voting and public demonstrations can put pressure to delay support for a low carbon transition. Care and pragmatic policies for the employment and local impacts of low carbon transitions will reduce the resistance to and the accelerate a low carbon transition. Furthermore, an awareness that concern for the welfare of the high-carbon employees will accelerate the low carbon transition will encourage the environmental camp to support a just transition. Thus, a virtuous circle of mutual support can be created.

Several organizations have created initiatives to revitalize coal impacted communities in the U.S.. The Appalachian Regional Commission (ARC) has awarded more than $316 million to 393 projects across 358 coal-impacted counties to provide resources to regions affected by energy transition (Bohannon, 2022). The U.S. Economic Development Administration (2022) has also pledged $300 million in support of coal communities while the Just Transition Fund (2022) provides financial and technical resources to the Navajo and Appalachian communities of the U.S. going through coal transition. Other organizations supporting communities undergoing coal transition include the Appalachian Citizen's Law Center (ACLC), the Allegheny Defense Project (ADP), the Small Business Administration (SBA) and the NRDC Natural Resources Defense Council (see Appendix in Hess et. al. 2021). In Europe, the European Commission has an initiative which connects stakeholders and provides technical assistance to regions undergoing coal transition (European Commission, 2022). Others include the Federal Ministry of Education and Research (Nijhuis, 2020; Climate Strategies, 2022; World Bank, 2022).

The results of this study ought to be interpreted with caution and several steps could be implemented to improve it. This study uses quarterly data between 2001 and 2020; a period marked by significant changes in the coal industry. However, an analysis using a dataset covering longer time period (and monthly data) could be used to provide robust estimates. Also, the inclusion of regional coal prices could provide interest findings. Finally, the use of spatial techniques could capture the spillover effects of these labor changes on neighboring states. These suggestions present areas for research in the future.

Availability of data and material (data transparency)

Available upon request from the authors

Code availability (software application or custom code)

Available upon request from the authors

Funding

N/A

Declaration of Competing Interest

N/A

Appendix

Table A

Table A
Variable names and descriptions.

Variable J2J flows from Coal to these industries	Description Description (The number of coal workers who moved to these industries)
Agriculture	Agriculture, Forestry, Fishing and Hunting
Oil	Mining, Quarrying, and Oil and Gas Extraction
Utilities	Utilities
Construction	Construction
Manufacturing	Manufacturing
Wholesale	Wholesale Trade
Retail	Retail Trade
Transport	Transportation and Warehousing
Information	Information
Finance	Finance and Insurance
Real_Estate	Real Estate and Rental and Leasing
Professional	Professional, Scientific, and Technical Services
Management	Management of Companies and Enterprises
Administrative	Administrative and Support and Waste Management and Remediation Services
Educational	Educational Services
Health	Health Care and Social Assistance
Arts	Arts, Entertainment, and Recreation
Accommodation	Accommodation and Food Services
Other	Other Services (except Public Administration)
Public	Public Administration

Source: U.S. Census Bureau (2021)

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