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PRODUCTION, PRICES, AND TECHNOLOGY: A HISTORICAL ANALYSIS OF THE UNITED STATES COAL INDUSTRY

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This article contributes to the literature regarding non-renewable resource extraction and production by using historical accounts and newly-collected county coal mining production, average value, and employment data, spanning the entire United States from 1900 to 1976, to analyze how fluctuations in prices and technology impacted the production decisions of the coal mining industry at the county level in the United States. It provides a description of how coal production, technology, and average prices changed throughout the twentieth century. It also provides evidence that coal producers responded in a significant way to variation in national and local coal prices, and that coal producers were aware of, and responded at the local level to, the behavior of past coal prices.

Introduction

The belief that economic actors respond to fluctuations in input costs and output price is central to the field of economics. There is also a general belief that conservation and responsible use of non-renewable resources is required for the success of future generations. The goal of this article is to understand how fluctuations in production, prices, and technology impacted the coal mining industry at the county level in the United States throughout the twentieth century. The article aims to identify the average net effect a change in price had on the production decisions of local coal producers, and how aware and responsive local producers were to past and future price variation. Further understanding of how non-renewable resource producers have responded to fluctuations in input costs and output price can help current and future policy makers more effectively analyze policies or initiatives that impact resource markets today, and in the future.

The coal mining industry experienced many changes during the twentieth century in the location and intensity of coal production, in technological advancements and mechanization, and in the average prices of coal obtained by local producers. The changes and variation in these measures will be chronicled and analyzed using both historical accounts of coal mining in the United States, and a newly-collected panel database of annual coal mining production, average value, and employment for the coal-producing counties of the United States from 1900 to 1976. These data provide measures of coal mining activity that vary across time and space, allowing a description of how coal production, prices, and technology changed in the United States. Mine-specific information on coal mining activity from 1900 to 1976, for the entire United States, is not available in the source documents, so the description and empirical analysis will be done at the county level. The average value of coal produced in a county is representative of an average price per ton of coal, where the buyer is responsible for the costs of transportation from the mine.

The net effects fluctuations in price and technology had on coal production decisions will be identified by using within-county variation across time, around a long-run average, that controls for time-invariant characteristics, like type or quality of coal mined, in each coal mining county. An instrumental variables (IV) approach is also used to isolate changes in local average coal prices independent of local production conditions, which allows for the identification of the net effects on production due only to changes in national equilibrium conditions. The estimation results should be interpreted as the average net effect changes in price have on the production decisions of local coal producers in the United States, after controlling for changes in technology and shocks that affect all counties in each state, like the export conditions faced by producers of coal. The analysis will also examine the timing of the impacts and will identify whether or not coal producers were aware of, and responsive at the local level to, the behavior of past and future coal prices. Numerous studies have examined the relationship between resource extraction and prices (Harold Hotelling 1931; Cynthia Lin and Gernot Wagner 2007; Robert Pindyck 1999; Margaret Slade 1982, 2001). This article contributes to the existing literature on the behavior of non-renewable resource prices and production by using long-run county data in the United States, spanning over seventy years, to analyze how fluctuations in prices and technology impacted the production decisions of the coal mining industry.

The results of the empirical analysis provide evidence that when the average county values of coal produced are used as the explanatory variable for local price, along with controlling for the level of technology, the relationship with county production is negative and significant. If local operators respond to increases in national price signals by increasing local production, this could have a negative effect on the local average value of coal produced, which the results suggest may have been occurring. The effect of county average value in the IV regressions, done to address this issue, is positive and implies increases in the average value of coal produced are associated with increases in the amount of coal produced within a county. The results are specific to within-county variation, the inclusion of state-by-decade interactions to control for changes in technology, and the isolation of the variation in local average values due only to changes in national equilibrium conditions. Increases in past county average values of coal produced are shown to have had a negative effect on current year coal production, suggesting coal operators may have been aware of the past behavior of coal prices, and were responding to them at the local level. The results also suggest the net effect changes in prices and technology had on production from 1900 to 1976 varied across time, potentially explained by a rise of coal production mechanization and increase in productivity during the time frame.

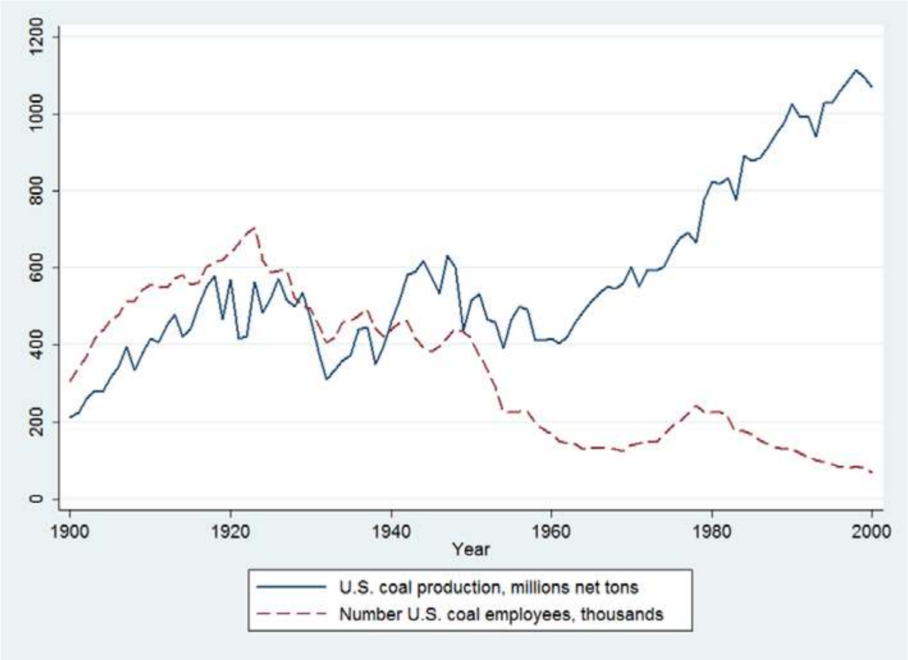
Coal Production in the Twentieth Century

Figure 1 shows the amount of coal produced in the United States from 1900 to 2000, obtained from the Statistical Abstract of the United States Census (Louis Cain 1800-2000). As defined in the source documentation coal refers here to "soft coal" and includes all bituminous, subbituminous, and lignite coal. Pennsylvania produced anthracite coal that is not included. The cyclical nature of coal mining production during the twentieth century is apparent, and is exhibited in the large increases and decreases seen in coal production over time. The biggest increases occurred from 1900 to World War One, during

World War Two, and from the early 1960s up through the end of the century. The largest decreases were experienced right after World War One, during the Great Depression, and in the late 1940s after World War Two. These large fluctuations in production are what have given rise to the "boom and bust" description of the coal mining industry, where community building and production of coal is followed by a population exodus of the area in times of contraction. Many authors have written on the impacts of this type of migration pattern on local areas (Harry Caudill 1962; James Sanders Day 2013; Crandall Shifflett 1991). Writing about the coal mining areas of eastern Kentucky in the 1950s and 1960s, Caudill (1962) paints an especially bleak picture:

> the coal and timber companies insisted on keeping all, or nearly all, the wealth they produced. They were unwilling to plow more than a tiny part of the money they earned back into schools, libraries, health facilities and other institutions essential to a balanced, pleasant, productive, and civilized society … fully three quarters of each county's spring crop of brighter boys and girls left immediately in quest of jobs in other states.

The rise of company towns in the early twentieth century came about partly in response to the early boom in coal mining activity. Shifflett (1991) writes that labor shortages and increased coal demand drove operators to build coal towns to attract workers. Company towns were often portrayed as a "filthy, crowded, and an exploitive environment dominated by autocratic coal bosses," but many oral histories of mining families paint a much more positive picture of life in coal towns (Shifflett 1991). These company towns provided essential services to miners and their families, and, since coal mining activity was often done in isolated and previously uninhabited areas, may have been the only place to purchase essential goods and services. It is a popular story that these towns, and especially the company store, exploited the miners and their families, but Price Fishback (1992) provides evidence this may not have been the case in many instances. The Great Depression was the beginning of the end for the institution of company towns as mines no longer needed to compete for labor.

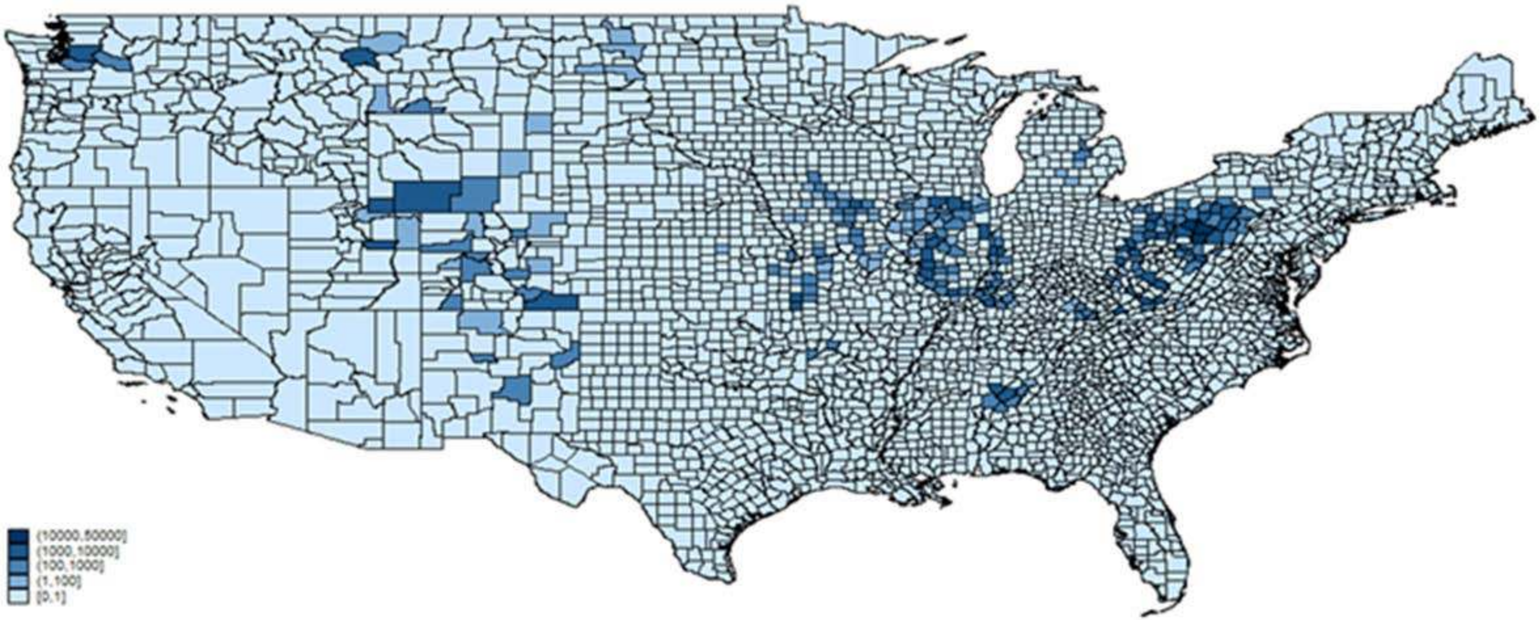


Source: Coal mining production and employment from Cain (1800-2000)

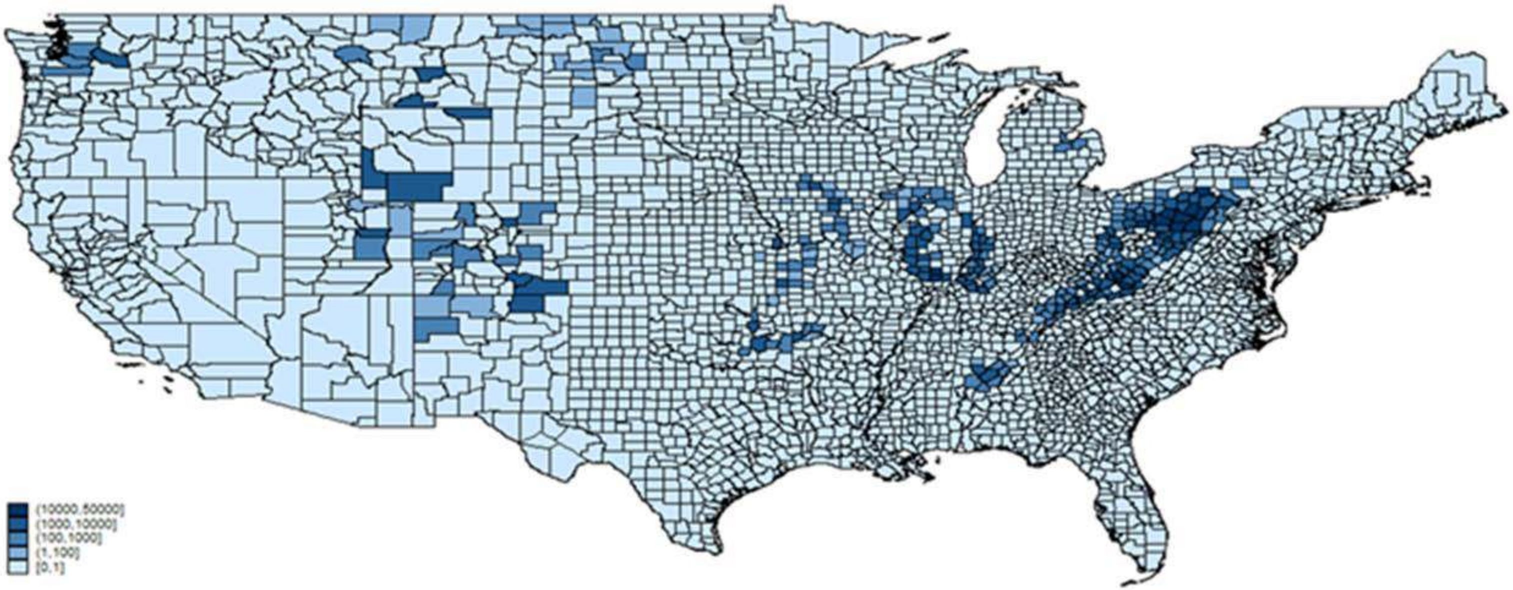
Figure 1

National Coal Production and Employment, Annual Series

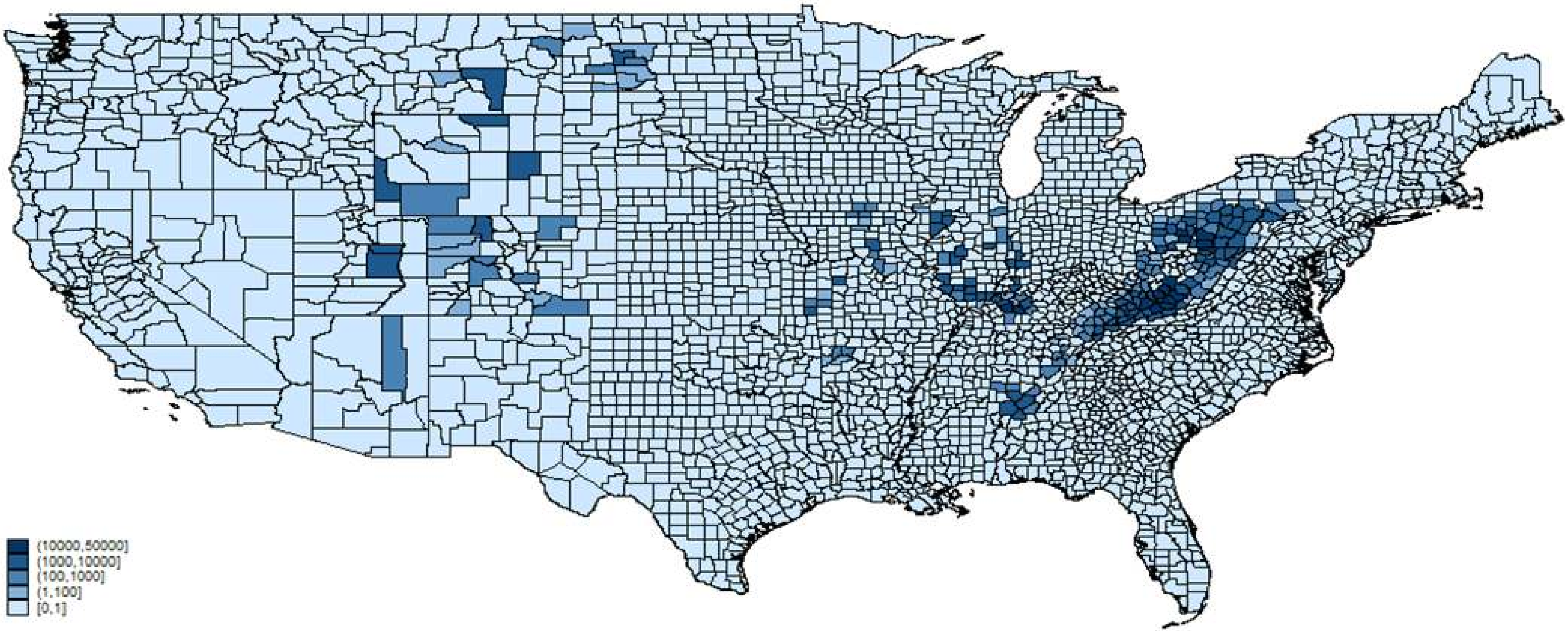
Figure 2 shows the location and intensity of all non-anthracite coal production by county from 1900 to 1970. For comparison purposes, all of the maps use 1940 county boundaries. The first thing to notice is that by 1900 there were already many counties reporting coal mining activity to the United States Geological Survey (USGS) and the Bureau of Mines. It is also very clear that major coal areas in West Virginia and Kentucky had yet to be opened. By 1920, these hard-to-reach areas of Appalachia were being mined heavily. Although the expansion of railroads was mostly complete by the late nineteenth century, many of the feeder lines required to service isolated areas in Appalachia were likely not yet built. Caudill (1962), Shifflett (1991), and Day (2013) all discuss the importance of railroads to the logistics of coal production, providing anecdotal evidence to this conclusion.



Panel A: County Coal Production (thousand net tons) in 1900



Panel B: County Coal Production (thousand net tons) in 1920



Panel C: County Coal Production (thousand net tons) in 1970

Sources: Coal mining information from USGS Mineral Resources and Yearbook documents 1882-1976.

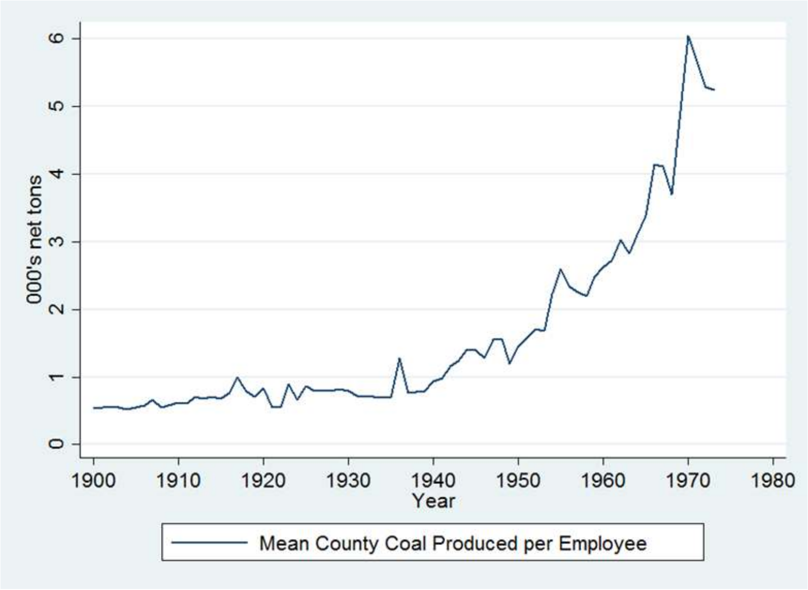
Figure 2

County Coal Production (thousand net tons) in 1900, 1920, and 1970

As shown in Figure 2, the geographical areas where coal mining activity occurred in the United States did not drastically change from 1900 to 1970, but the intensity of the activity in each area did change over time. In the post-World War Two period, there was a very clear consolidation of coal mining operations away from areas in the West and Midwest into Appalachia. Although there was still mining in the Illinois coal basin, and west of the Mississippi River, in 1970, the number of counties mining coal, and the intensity with which they were doing so, decreased significantly relative to earlier periods.

The location of coal reserves was well classified by the late nineteenth century, so what, if anything, explains the marginal changes in coal production location and intensity? A major factor was likely the change in the cost of accessing coal due to changes in technology. The room and pillar method of underground mining was the dominant method until the rise of mechanization in the 1930s and 1940s. In this method shafts would be dug down, or into the side of a mountain, for access to the coal seams. Once at the coal face, miners began a process with four steps to get the coal: undercutting, drilling, blasting, and loading (Day 2013). The work was done by hand, where miners would tunnel into the coal seam off main access tunnels, undercut the coal face using a pick axe, drill a hole into the face using a hand powered auger, blast the coal face, and shovel the blasted coal into trams or cars. There was room for improvement to this method, as some "pillars" of coal had to be left to avoid catastrophic collapse. Shifflett (1991) describes mechanization as "a solution that allowed operators to lower the costs of production and, when needed, to produce more coal with less labor," and that mechanization occurred unevenly across Appalachia.

Figure 1 illustrates that mechanization allowed more coal to be produced with less labor. There is a strong positive correlation in employment and production from 1900 to 1920, but after 1920 there is a steady decline from the apex of employment in 1923, at a little over 700,000 employees nationally, all the way up to 1970. In fact, by 1970, 140,000 employees produce roughly the same amount of coal that 640,000 employees produced in 1920. There are small increases and decreases in employment from 1940 to 2000, that appear to be correlated with changes in production, but overall the trend is strongly downward. This trend is also present in the productivity measure in Figure 3, where coal production per employee increases significantly after 1940. This increase in productivity is strongly related to the level of mechanization present in the coal mining industry. The increase in mechanization significantly lessened the cost of accessing underground coal and "drastically lessened the number of workmen needed in the mining process" (Caudill 1962).



Sources: Coal mining information from USGS Mineral Resources and Yearbook documents 1882-1976.

Figure 3

Annual County Coal Production per Employee

One of the first innovations in underground coal mining was the electrically powered cutting machine. Earlier versions of cutting machines in the 1890s were run with compressed air. This machine replaced the pick axe as the tool of choice to undercut the coal face in the early twentieth century. By 1920, two-thirds of bituminous coal was being mechanically undercut (Day 2013). The introduction of the mechanical loader in the 1920s complemented the mechanical cutting machine. The mechanical loader made the last task, shoveling the coal into a tram or car, much more efficient, by allowing the miner to shovel the coal onto a moving conveyor that delivered the coal onto the tram or car. According to Shifflett (1991), the mechanical loader resulted in a 20 percent rise in productivity, as measured in tons per man day, between 1930 and 1950.

While these are important improvements, the real game-changer was the introduction of the continuous miner in the late 1940s. This machine replaced both the mechanical cutter and loader by combining both functions into one machine. Instead of undercutting, blasting, and shoveling, a large revolving drum with sharp teeth at the front of the machine would cut into the coal face and then dump the coal onto a conveyor belt. Day (2013) states that "a three-man crew performed the work of seventy hand-loaders" and Shifflett (1991) says "productivity in southern Appalachia rose nearly 100 percent" in the 1950s due to the continuous miners. The continuous miner also changed the fundamentals of how underground mining was performed. The continuous miner allowed the rise of "long-wall" mining, where coal is extracted from a very long face. This eliminated the need for rooms and pillars, and would extract virtually all coal from the seam (Day 2013). The continuous miner also changed how miners were paid, from piecework based on tonnage, to standard wages on a per-hour basis (Day 2013).

The long-wall method was underground mining's answer to the rise of surface, or strip, mining during this time period. Caudill (1962) says that "by 1950, strip mining was not only feasible but was increasingly profitable" in the mountains of eastern Kentucky. The real benefit to strip mining is that it eliminates the need for men to go underground. Generally, strip mining uses large machines to remove very large amounts of rock at one time, which is then sorted and transported to market. It does this by bulldozing the mountain of vegetation and soil, and then explosives are used to break up the rock and get to the coal seam. Once this is done, more holes are drilled into the coal and explosives are used to break up the coal seam. Large power shovels then load the coal into trucks, which carry it off to be cleaned and sent to market. According to Caudill (1962), "six or eight men can dig more coal than five or six times their number can mine underground" and "they can produce a ton of coal for little more than half the cost imposed on a competitor in a deep pit." The strip mining method produces large amounts of coal, with lower levels of labor costs and danger, but it is not without costs. Caudill (1962) says that "after the coal has been carried away vast quantities of the shattered mineral are left uncovered. Many seams contain substantial quantities of sulphur, which when wet produces toxic sulphuric acid. This poison bleeds into the creeks, killing minute vegetation and destroying fish, frogs, and other stream-dwellers." Surface mining also causes stream silting, water and air pollution, and soil erosion, all of which can pose significant environmental issues (Day 2013).

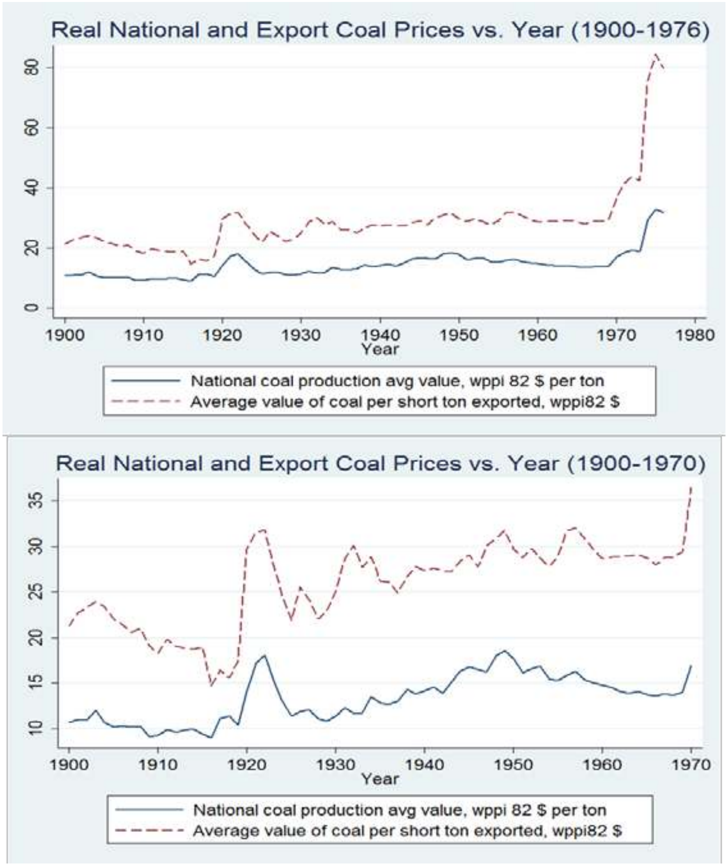
Research Design

The following sections aim to expand upon the historical description provided above and identify how fluctuations in prices and technology impacted the production decisions of the coal mining industry. An obvious first choice for price is the average value of coal produced per ton in a county, which is representative of an average free-on-board mine price where the buyer is responsible for the costs of transportation from the mine. This is also known as the mine gate price. Changes in the average value of coal produced within a county over time can result from changes in national prices, but are also impacted by the behavior of local coal producers. This means the observed county average value of coal produced could be both a cause, and a result of local coal production. This is obviously endogenous to coal production in a given year. For this reason, alternative measures of coal prices must be explored to isolate variation in the average value of coal produced that is independent of local production decisions.

The variation in national prices of coal and the cost to transport coal to market are two potential drivers of within-county variation in local coal prices. Differences in the quality or type of coal mined across counties could result in large cross-sectional variations in prices, but the empirical analysis in this article will focus on within-county variation, where it is assumed the quality or type of coal mined will be similar across time. Predicted local coal prices can be constructed from the national price of coal, distance to market, and average railroad transportation costs. This predicted local coal price reflects the revenue per ton left over after paying the transport costs from the mine location to a potential market, and is analogous to the observed average value of coal produced per ton in a county. This predicted local coal price will provide a measure of the annual variation in prices that local producers may have faced due to changes in national conditions. This value is likely correlated with the amount of coal production in a county because increases in the national prices should be associated with expansions in local coal mining activity.

Variation in two measures of national coal price will be considered, the coal export price per ton and the national average value of coal produced per ton. The export price of coal was estimated by calculating the coal export price per ton from the value of coal exported from the United States in a given year, divided by the number of tons exported. This information was obtained from the Statistical Abstract of the United States Census from 1919 to 1989 (United States Department of Commerce 1878-1994). For the years 1867 to 1918 this information was obtained from the USGS and Bureau of Mines Mineral Resources of the United States documents (USGS 1882-1931). The national average value of coal produced per ton was also obtained from the Statistical Abstract of the United States Census (Cain 1800-2000), and provides an alternate measure of the national price of coal. The average value of coal produced per ton is representative of an average free-on-board mine price for the entire United States. Real prices are calculated using Bureau of Labor Statistics wholesale and producer price indexes (hereafter "wppi") obtained from the Statistical Abstract of the United States Census (Christopher Hanes 1890-1997). Figure 4 shows the variation in the real national and export coal prices per ton (real price adjusted to 1982 dollars) from 1900 to 1976. The two panels contain the same information, but the bottom panel excludes the post-1970 period to allow for a closer inspection of the variation up to 1970.

One common explanation for the behavior of non-renewable resource prices is known as the Hotelling rule, which states that the shadow price of a resource stock, which is equal to the market price minus the marginal cost of extraction, should be equal to the interest rate (Hotelling 1931). If constant marginal extraction costs are assumed and there is no technological progress, then resource prices should rise over time. Many studies have examined this prediction and have shown that resource extraction and prices do not empirically follow this pattern throughout the twentieth century (Lin and Wagner 2007; Pindyck 1999; Slade 1982), showing the importance of incorporating technological change into any investigation of non-renewable extraction. Pindyck (1999) investigates oil, coal, and natural gas prices from 1870-1996. He finds evidence that nonstructural forecasting models of depletable resource production and pricing should incorporate mean reversion, taking up to a decade to occur, to a stochastically fluctuating trend line. Slade (2001) also finds evidence of mean reversion in mining output prices in her investigation of copper mining in Canada.



Sources: Coal export price from United States Department of Commerce 1878-1994 and USGS Mineral Resource documents 1867-1918. National average value of coal from Cain (1800-2000).

Figure 4

Real Coal Prices, Annual Averages (1900-1970 and 1900-1976)

Figure 4 provides visual evidence that national coal prices from 1900-1976 exhibit the behavior described by Pindyck (1999) and Slade (2001). Price increases are universally followed by decreases, and the overall pattern is a slow and varying upward trend in prices, up to the early 1970s. Although mean reversion and trends seem to be present in the data series, Figure 4 does provide evidence of annual variation in the national price of coal. As can also be seen, the export price of coal and the national average value of coal produced per ton move together, with the export price of coal always being higher. This difference could be due to additional transportation or transaction costs required to export coal, or may reflect differences in quality of coal exported. If changes in price and not absolute levels are important, then these two national measures of coal price should be equally effective.

Data

For this article I collected, compiled, and digitized a long-run panel database of annual county-level coal mining activity from 1900 to 1976 for the coal-producing counties of the United States. The annual coal mining production, average value, and employment data from 1900 to 1931 were acquired from the USGS and the Bureau of Mines Mineral Resources of the United States documents. These documents were published from 1882 to 1931 and contain annual county-level coal mining production information (USGS 1882-1931). The underlyingcoal mining data in these documents came from the efforts of multiple sources: commercial mines, traffic managers of coal-originating railroads, local coal operator associations, and state mine inspectors. The United States coal mining data for the years 1932 to 1976 were obtained from USGS and the Bureau of Mines Mineral Yearbook documents. These documents have been published since 1932 and also contain annual county-level coal mining production information (USGS 1932-1976).

After 1976 the responsibility for collecting and reporting coal production at the county level changed. I have been unable to locate county-level information from 1977 to 1982, which is why the analysis in the article stops at 1976. Mine-specific information on coal mining activity from 1900 to 1976, for the entire United States, is not available in either set of documents.

The reported county average value of coal produced per ton is representative of a county average free-on-board mine price, where the buyer is responsible for the costs of transportation from the mine. The documents also specify the type of coal being mined in the county as bituminous, lignite, or anthracite, but do not specify a difference between bituminous and subbituminous types of coal. Unfortunately, this information is not available for all coal-producing counties, for all years 1900 to 1976. Fortunately, the type of coal mined in each county does not change for those counties that do report this information, which means that an empirical analysis that controls for time-invariant characteristics within the county will control for the type of coal being mined. Anthracite producing counties in Pennsylvania were dropped from the analysis because average value data were not reported at the county level for many of the years, resulting in a total of 563 non-anthracite (bituminous and lignite) coal-producing counties.

Coal data were only obtained for those counties that reported data in the Mineral Resources and Yearbook documents. Counties with significant coal operations report their production consistently. If the county did not report coal production in a specific year, then the coal variables were set to "missing" for that county and year. The county may not have reported coal production in a year for three different reasons: it actually did not produce any coal, it produced coal and reported activity in the documents combined with other counties, or it produced coal but for some reason just did not report activity. I am able to see whether the county was combined with others in the original sources, but I am not able to distinguish between the other two possibilities, which is why I set the coal variables equal to "missing" instead of zero. These counties are the marginal producers of coal. I will explore whether or not excluding these non-continuous reporters impacts the results of the analysis. I will also explore whether or not setting these missing values to zero impacts the baseline results. The only systematic gap is in the early 1930s where county-level data on coal mining activity do not seem to exist in either document, potentially due to conditions in the country at the time or a switch in responsibilities regarding collection. For this time period, county-level data were created from reported state level data, and the ratio of county to state production, before and after the gap.

The use of county data from 1900 to 1976 means the issue of county boundary changes must be addressed. County boundaries have changed significantly from 1900 to 1976 and could significantly impact the analysis of coal mining production at the county level. I have combined counties into a larger "new" county if there were any changes from 1900 to 1970. I used the Richard Forstall (1996) document to help me determine which changes captured in the Atlas of Historical County Boundaries (Newberry Library) were "significant" and required attention. This means that if a county was created in 1910 from another county that had been in existence since 1870, these two counties were combined and are treated as one county in my dataset for the whole time period. The result of the process is a dataset that contains 505 coal-producing counties, 191 of which report their operations continuously. Summary statistics are available upon request.

Empirical Model

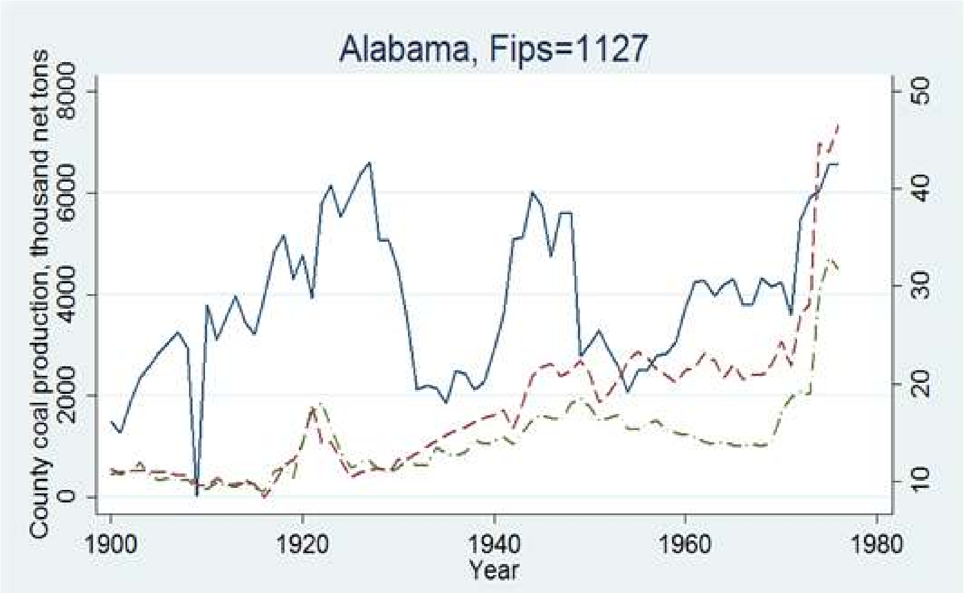
The net impacts of changes in price and technology on coal production are estimated at the county level in the United States with the following equation:

$$CoalProduction_{ct} = \delta_0 + \delta_1 LocalCoalPrice_{ct} + \delta_2 Technology + \eta_c + \varepsilon_{ct} \quad (1)$$

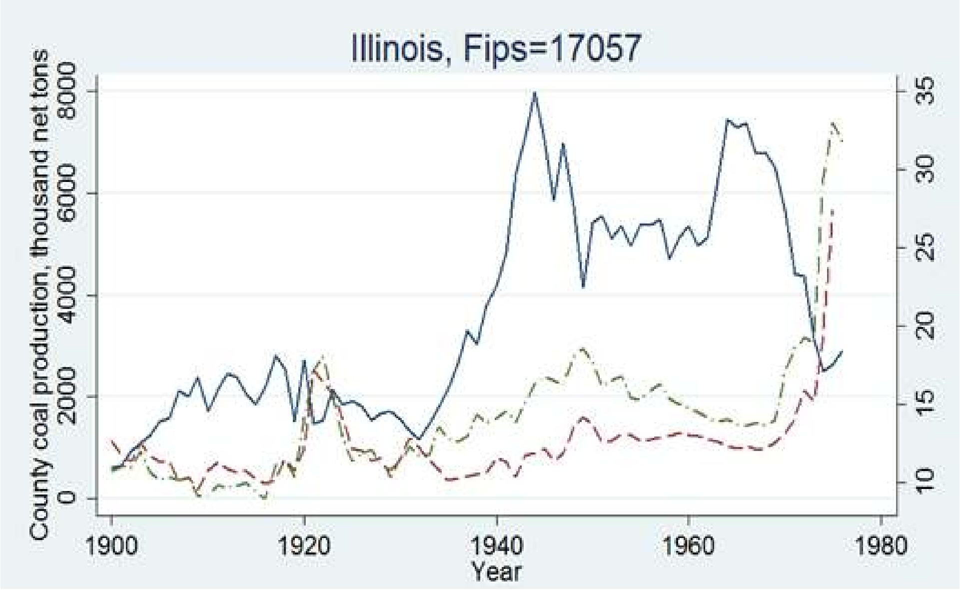
where $CoalProduction_{ct}$ is the amount of coal produced (thousand net tons) in a county and given year. The coefficient of interest is the coefficient for the real average value of coal produced in the county in the same year, $LocalCoalPrice_{ct}$. County fixed effects are included in the preferred specifications to control for any time-invariant characteristics at the county level. These would include: type or quality of coal mined, geography, ruggedness, elevation. The impact of *Technology* is modeled a few different ways. The first is through the use of year fixed effects, which account for changes in technology over time by controlling for annual shocks that affect all counties in the United States. This would also include national shifts in other areas, like the energy production of coal in the United States, or the annual export conditions faced by producers of coal in the United States. The second is through the use of a dummy variable for each decade from 1900 to 1976, interacted with a dummy variable for each state. Each interaction variable will provide the effect that being in that decade and in that state has on the amount of coal production within each county, relative to a base level. This is similar to using state-by-year fixed effects, but it provides a rough measure of changes in technology over time versus controlling for all things that vary year-to-year for all counties in each state. This provides a rough estimate of the effect of technological change, without getting rid of the majority of the variation in prices on an annual basis.

The estimation strategy uses within-county variation across time in price, around a long-run average, to identify the effects on coal production, after controlling for annual or state-by-decade shocks or changes in technology. The results should be interpreted as the average net impact changes in local price have on annual coal production in counties that possess available coal reserves. Figure 5 provides evidence of within-county variation in coal production and real average value per ton of coal versus time for three coal-producing counties in Alabama, Illinois, and West Virginia. Figure 5 also provides evidence of cross-sectional differences across counties in real average value of coal produced in a given year. The observed county average values do seem to generally move together with the national average value of coal produced, but there are significant differences in the amount of change in average value and the absolute level of average value across these three counties. Figure 5 also shows how coal production changes within these three counties from 1900 to 1976. At first glance, it is not clear how producers are responding to price signals in these counties, but that there is significant variation in production and prices over space and time. Graphs for all coal-producing counties are available, but are not included due to space and readability concerns.

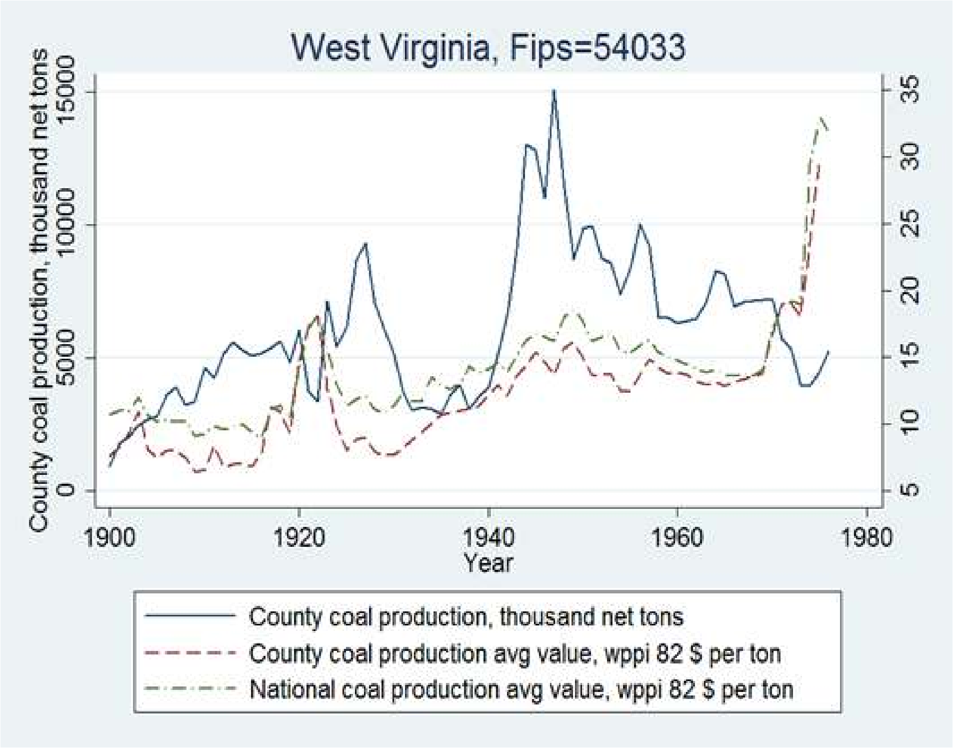
As discussed previously, $LocalCoalPrice_{ct}$ is endogenous to annual county coal production when the county average value of coal produced is used as the explanatory variable. For this reason, I will use an IV strategy, where the predicted local price in each county is used as an instrument for $LocalCoalPrice_{ct}$. The predicted local coal price will provide variation in the local average value of coal due to changes in national coal price and transportation costs, which will be used to show how producers respond to price variation. These two measures should be strongly correlated, but an empirical analysis to verify this assumption is required. It is highly unlikely that the national coal price was determined or heavily influenced by county production because each county is only going to provide a small share of the national and world amounts of coal. It is also unlikely national



Panel A: Walker County, AL



Panel B: Fulton County, IL



Panel C: Harrison County, WV

Sources: Coal mining information from USGS Mineral Resources and Yearbook documents 1882-1976. National average value of coal from Cain (1800-2000).

Figure 5

Annual Coal Production and Prices in Three Coal-producing Counties

coal prices would have any direct impact on county production other than through changes in local prices.

I calculate a predicted local coal price, which reflects the revenue per ton left over after paying the transport costs from the mine location, to a potential market, with the following equation:

$$Z_{ct} = P_t - D_c * RR_t \qquad (2)$$

where P_t is the real national price of coal described previously. The second part of the calculation is a measure of distance to a potential market for each county, D_c. Distance to a potential market is estimated by measuring the minimum distance between the county and where the commodity could potentially be sold and/or exported. The calculation was done using latitude and longitude of county seats to the nearest (Euclidean distance) major city. The final part of the calculation is a measure of the annual average national railroad freight rates in revenue per ton mile, obtained from the Historical Statistics of the United States (Cain 1890-1980, 1865-1890). The changes in national prices provide variation over time, and the transportation cost estimate derived from the product of distance to market and average national rail freight rates for each county provides cross-sectional variation. How counties respond differently over time to these national changes in price provides the within-county variation. The exclusion restriction is satisfied by using national prices of coal and rail freight, and a distance measurement not dependent on local infrastructure, to construct the predicted local coal price.

Local Coal Prices

It is assumed that changes in national prices reflect shifts in national, and international, equilibrium prices for coal. An increase in national prices could be the result of an outward shift in demand for coal, increasing both price and quantity. In this situation, how well does the calculation of predicted local prices align with changes in the observed real average value of coal produced at the county level? A one-to-one relationship would imply coal producers at the county level vary annual production, and hence average value, in accordance to changes in national and international conditions. Something other than a one-to-one relationship implies there are differences in local conditions relative to national supply and demand. It could be there is an outward shift in supply at the local level. If the shift in supply is large enough, we could observe a local average value of coal produced below that predicted from changes in national and international equilibrium.

An empirical analysis is required to determine how well the prediction of local prices aligns with observed county average values of coal produced. This will be done using a standard regression framework where county average value of coal produced is the outcome variable and the predicted local price is the explanatory variable. The results of the empirical analysis are shown in Table 1. Table 1 shows results using predicted local prices based on export prices and national average values. Columns one to three show the regression results using ordinary least squares, and columns four to six incorporate county fixed effects. Both predicted local prices have a positive relationship with the real average value of coal at the county level. The results are very similar without county fixed effects, but once these are added the coefficient on the national average value prediction gets much larger, but is still less than one. These results provide evidence that the predicted local coal price and observed county average value of coal are positively correlated, but the county average value of coal produced does not increase or decrease as much as changes in national prices and transportation costs would predict. This leads me to believe there is a response happening at the local level, and that changes in the predicted local prices represent what I will call the "national" effect.

Table 1

Average County Value of Coal Production versus Export and National Prices 1900-1976

	(1)	(2)	(3)	(4)	(5)	(6)
Real Average Value Coal Exported	0.328*** (0.0138)			0.349*** (0.0136)		
Predicted Local Price (Export Price Based)		0.188*** (0.0203)	-0.0820** (0.0335)		0.298*** (0.0133)	-0.0140 (0.0658)
Real National Average Value Coal Produced	0.838*** (0.0349)			0.899*** (0.0345)		
Predicted Local Price (National Average Value Based)		0.162*** (0.0368)	-0.0820** (0.0335)		0.506*** (0.0313)	-0.0140 (0.0658)
County FE	No	No	No	Yes	Yes	Yes
Year FE	No	No	Yes	No	No	Yes
Observations	17761	17761	17761	17761	17761	17761

Notes: Standard errors in parentheses, clustered at county level. Includes county corrections 1900-1970. Average value defined as dollars per ton of coal produced, wppi82 dollars. $* p < 0.10$, $** p < 0.05$, $*** p < 0.01$

Results: Production versus Local Prices

Table 2 shows the results of the baseline empirical model described previously. The first two columns use OLS regression without county fixed effects. Columns three and four include county fixed effects, and add either year fixed effects or the state-by-decade interaction variables. The relationship with county-level production is negative and significant in the fixed effects regressions when the real county average value of coal is used as the local price explanatory variable. This implies increases in local coal prices are associated with decreases in the amount of coal produced. Thinking about local prices as a result, instead of a cause, provides another way to interpret these results. Local production impacts the local average value of coal produced. If local operators respond to increases in national price signals by increasing local production, this could have a negative effect on the local average value of coal. If the response is large enough, local values could actually decrease. These negative results suggest this may have been occurring, and that supply side responses were dominating national shifts in equilibrium prices. Another way to interpret this result is to believe it says something about operator behavior. When prices increase, further increases are then expected, and production is cut back today to gain in the future. I will investigate this further in later sections.

Table 2

County Coal Production versus County Average Value and Technology
1900-1976

	(1)	(2)	(3)	(4)	(5)	(6)
Real County Average Value Coal Produced	-13.13 (14.58)	-1.915 (19.49)	-29.67*** (10.54)	-29.02* (17.44)	16.07* (8.731)	328.3 (247.5)
County FE	No	No	Yes	Yes	Yes	Yes
Year FE	No	No	No	Yes	No	Yes
State Decade Dummies	No	Yes	Yes	No	Yes	No
Observations	16777	16777	16777	16777	16757	16757
Kleibergen-Paap F-Stat					293.8	3.595

Notes: Standard errors in parentheses, clustered at county level. Includes county corrections 1900-1970, coal production in thousand net tons.
∗ $p < 0.10$, ∗∗ $p < 0.05$, ∗∗∗ $p < 0.01$

The IV regressions are done to address the endogeneity issue and isolate the variation in the local average value of coal due only to changes in national and international equilibrium conditions. The effect of county average value in the IV regressions, shown in columns five and six, becomes positive. The first stage is extremely strong as measured by the KP F-Statistics, which is to be expected given the results shown in Table 1. The coefficient of 16.07 in column five of Table 2 shows that at the county level producers respond positively to variation in the local price of coal, and that a one standard deviation change in price leads to a three percent of a standard deviation change in coal production. The addition of year fixed effects, along with county fixed effects, creates a situation where the estimated coefficient becomes imprecise and is not significant, and weak instrument bias is a major concern. This result shows that using county and year fixed effects together may not be desirable when using the predicted local price.

These results show increases in the average value of coal produced are associated with increases in the amount of coal produced within a county. The result is specific to within-county variation, the inclusion of state-by-decade interactions to control for changes in technology, and the isolation of the variation in the local average value of coal due only to changes in national and international equilibrium conditions. The empirical analysis done in Table 2 was repeated using a log-log specification, instead of a linear levels analysis, the results of which are available upon request. The results for all specifications were similar in sign to the key results in Table 2, and the strength of the first stage of the instrument was also comparable. This implies the previously discussed results are not dependent on the linear specification.

Sensitivity to Missing Observations

The econometric analysis above leaves as "missing" any county-level observation if it was not reported in the Mineral Resources or Yearbook documents. It may be a reasonable assumption that in those years there was either no or very little commercial activity. For this reason, the analysis done in Table 2 was repeated using data for production, average value, and employment that was changed to zero instead of "missing" for these observations. Coal production in a county will be set equal to zero if it was missing information on both value and production. This increases the number of observations used in the analysis, and decreases the means for all the variables used in the analysis. Summary statistics for this dataset are available upon request.

The results of this analysis are presented in Table 3. The impact of the local average value of coal on production is positive with the inclusion of county and state-by-decade fixed effects. This is a change relative to the results shown in Table 2. The estimates for the IV regression are also positive, but are not statistically significant. The results suggest an opposite relationship between local prices and production, relative to that suggested in Table 2, when opening and closing of marginal mining areas at the county level is taken into account. These results suggest representing the

Table 3

County Coal Production versus County Average Value and Technology 1900-1976, Zeros Dataset versus Continuous Reporting

	(1)	(2)	(3)	(4)	(5)	(6)
Zeros Dataset:						
Real County Average Value Coal Produced	92.29*** (9.971)	78.42*** (8.390)	13.98*** (3.999)	22.77*** (5.637)	9.765 (8.344)	234.0 (162.1)
Observations	33549	33549	33549	33549	33549	33549
Kleibergen-Paap F-Stat					142.4	1.595
Continuous Reporting:						
Real County Average Value Coal Produced	18.38 (20.04)	32.22 (27.03)	-41.72*** (13.98)	-48.05* (25.14)	19.31* (9.886)	234.8 (175.4)
Observations	11667	11667	11667	11667	11667	11667
Kleibergen-Paap F-Stat					270.0	5.435
County FE	No	No	Yes	Yes	Yes	Yes
Year FE	No	No	No	Yes	No	Yes
State Decade Dummies	No	Yes	Yes	No	Yes	No

Notes: Standard errors in parentheses, clustered at county level. 191 counties continuously report coal production within this time period.
$* p < 0.10$, $** p < 0.05$, $*** p < 0.01$

opening and closing of mining operations by assuming counties without continuous reporting have no coal mining activity, has significant consequences to the analysis of prices, production, and technology. This is not surprising, as it would be expected that when all the zeros are taken into account, the impact of price on opening or shutting mines is very large and volatile.

I further explore the opening and closing decisions of these marginal mines and how their responsiveness may be different than counties with continuous operations by repeating the analysis from Table 2 using only counties that continuously report their coal production activity. This sub-sample contains 191 combined counties throughout the United States. The results of this analysis are also presented in Table 3. The results are very similar to the results shown in Table 2, where increases in the average value of coal produced are associated with increases in the amount of coal produced within a county. The results in Table 3 suggest that these continuously reporting counties are driving the results shown in Table 2, and that there is a very different relationship between production, prices, and technology for mines that continuously produce, and for those that open and close during the time period. Pindyck (1999) and Slade (2001) find evidence of mean reversion in mining output prices in the United States and Canada. Figure 4 provides evidence of this behavior, where price increases are followed by decreases and vice versa. Were coal operators in the United States aware of this behavior? If so, did they respond and change their behavior accordingly? Operators may have been able to increase profits by holding back on production today for more production tomorrow, if they were fairly confident that there would be price increases in the future.

Producer Responsiveness to Past and Future Prices

How effective were the operators at predicting and responding to changes in price? Do mines produce a bit less just before prices increase? According to the analysis shown in Table 4, there is not significant evidence for this behavior. The fixed effects regression results in column one show that increases in both this year’s and next year’s average value of coal produced has a negative effect on coal production today, but that only the coefficient for this year’s average value is statistically significant. Again, the average value of coal produced could be both a result and a cause of local coal production, so endogeneity is a concern. The IV results in column three address this issue by isolating the variation in current and future local average values of coal driven by national price shifts, and show that increases in future local average values have a negative, but not significant, effect on current coal production today. These results suggest coal operators may have been aware, but were not significantly responding to, the behavior of future coal prices.

Table 4

County Coal Production versus Next Year's Average Value and Technology 1900-1976

	(1)	(2)	(3)	(4)
Real County Average Value Coal Produced	-36.42*** (9.619)	-23.18 (15.85)	28.59** (12.48)	732.0 (874.7)
Real County Average (t+1) Value Coal Produced	-4.429 (7.196)	-15.69 (10.56)	-8.070 (9.116)	-358.5 (786.1)
County FE	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	Yes
State Decade Dummies	Yes	No	Yes	No
Observations	14974	14974	14956	14956
Kleibergen-Paap F-Stat			39.65	0.261

Notes: Standard errors in parentheses, clustered at county level.
$*$ $p < 0.10$, $**$ $p < 0.05$, $***$ $p < 0.01$

Would it be more effective to use previous measures of coal price in the empirical analysis of the responsiveness of coal operators to variation in coal prices? It is plausible to surmise local coal operators used previous coal prices in setting their expectations for current and upcoming coal operations. There is also the possibility that there was a lag to expanding or contracting operations in response to changes in price. Table 5 repeats the analysis done in Table 2, but includes two previous years of the county average value of coal in the specification. The results suggest operators may have been influenced by past price conditions when making production decisions today. Columns one and two reinforce the idea that local coal prices are negatively related to coal production if the endogeneity issue is not addressed. The IV results in column three show that past local average values of coal have a negative impact on current year coal production, and this year's average value has a positive influence. This implies coal operators may have been influenced by past realizations of local coal prices. It also suggests there was a complex relationship between past, current, and future coal prices with operator behavior.

Table 5
County Coal Production versus Lagged Average Value and Technology
1900-1976

	(1)	(2)	(3)	(4)
Real County Average Value Coal Produced	-19.45** (8.213)	-18.08 (11.17)	50.60*** (12.26)	424.1 (478.8)
Real County Average (t-1) Value Coal Produced	-15.73*** (4.782)	-27.23** (10.65)	-26.74** (12.31)	448.0 (554.5)
Real County Average (t-2) Value Coal Produced	-26.46** (12.95)	-25.02 (17.26)	-56.76*** (21.92)	-644.9 (957.8)
County FE	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	Yes
State Decade Dummies	Yes	No	Yes	No
Observations	13819	13819	13812	13812
Kleibergen-Paap F-Stat			17.06	0.201

Notes: Standard errors in parentheses, clustered at county level.
∗ $p < 0.10$, ∗∗ $p < 0.05$, ∗∗∗ $p < 0.01$

Sample Year Variation

Do the impacts change over time throughout the sample? To answer this question I split the sample from 1900-1931 and 1940-1976 and ran the analysis from Table 2 on each sub-sample. I eliminated the 1930s due to issues with data reporting in that decade. The results of this analysis are contained in Table 6. The results in columns one and three show much larger price effects in the period 1900 to 1931, versus the entire sample. The magnitudes of the effects shown in Table 6 are smaller for 1940-1976 for the IV regression in column three. The results suggest the instrument is much stronger in the first stage after 1940, but that the resulting impact on county coal production is also much smaller relative to the period 1900 to 1931. A potential explanation for the increased IV strength would be an increase in the integration of regional markets across the country over time. It could also be due to many other things, like changes in the contract structure of coal sales and purchases. The results suggest there were some changes in the relationship between production, prices, and technology during the time period 1900 to 1976. The rise of coal production mechanization and increase in productivity, shown in Figure 3 and discussed above, could also be a potential driver of these differences.

Finally, the empirical analysis done in Table 2 for coal production and prices was repeated using a sample that did not contain any observations after 1969. This was done to check that the previous results were not driven solely by the large increase in prices shown in Figure 4. The results of this analysis are shown in Table 6. The IV results in column three are positive and statistically significant, but are much larger in magnitude relative to the baseline result in Table 2. Upon inspection of the behavior of production and prices after 1970 in Figures 1 and 4, this result is not surprising. Figure 4 shows a large increase in the mean level of local prices after 1970, but Figure 1 shows the level of production staying relatively constant, or increasing slightly, until the late 1970s. Also, the increase in national production shown in Figure 1 is not as large in percentage terms as the increase in prices during this time period. Excluding this portion of the data should strengthen the positive relationship between production and local prices.

Table 6
County Coal Production versus Average Value and Technology 1900-1931, 1940-1976, 1900-1969

	(1)	(2)	(3)	(4)
<u>1900-1931:</u>				
Real County Average Value Coal Produced	-44.77*** (9.252)	-33.71*** (10.33)	77.05*** (24.50)	1148.4 (1432.1)
Observations	7405	7405	7392	7392
Kleibergen-Paap F-Stat			60.20	0.735
<u>1940-1976:</u>				
Real County Average Value Coal Produced	-24.92*** (8.737)	-51.44*** (16.07)	7.081 (7.924)	155.4 (259.2)
Observations	9098	9098	9074	9074
Kleibergen-Paap F-Stat			510.0	6.003
<u>1900-1969:</u>				
Real County Average Value Coal Produced	-41.57** (17.91)	-16.89 (21.46)	75.69*** (25.37)	614.9 (546.8)
Observations	15682	15682	15662	15662
Kleibergen-Paap F-Stat			93.54	1.458
County FE	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	Yes
State Decade Dummies	Yes	No	Yes	No

Notes: Standard errors in parentheses, clustered at county level.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Technological Change and Coal Production

The empirical results shown in this article only control for technological changes. I would like to take the analysis further, using variation at the county level that can be exploited, and quantify the impact of technological change on production. I have created a measure of production per employee and in Figure 3 have shown how the mean for this measure changed over time for all coal-producing counties in the sample. This is a measure of productivity, and is a good proxy for the current level of technology at the county level. There are some large gaps in the reporting of this measure at the county level (1969, 1971, and 1974-1976), but the plot clearly shows an increase in this measure over time, with the large increase starting in the 1930s. This is not surprising given the previous discussion regarding the introduction of coal industry technological enhancements, and is also consistent with the national production and employment trends shown in Figure 1.

Unfortunately, the measure of productivity represented in Figure 3 is endogenous to coal production in a county. If the number of employees stays the same but production increases, it can be assumed that each employee is more efficient and the level of technology has increased. The measure of production per employee would increase, and an estimate of the impact on county coal production would be positive. If production stays the same from one year to the next, but the number of employees decreases, the measure of production per employee would increase, but the amount of coal produced would stay the same. The relationship between technology and production is positive, as fewer workers are producing the same amount, but the analysis will not identify the effect. I have done some preliminary work with the measure of productivity as my outcome variable. Preliminary results do not provide strong evidence that variation in local prices had a direct influence on the level of productivity in the coal industry after controlling for changes in technology. Further exploration of the relationship between technological change and coal production is a topic for future research.

Conclusion

This research contributes to the existing literature by identifying how non-renewable resource producers responded at the county level to fluctuations in input costs and output prices in the United States' coal mining industry over a seventy year time span. I collected, compiled, and digitized a long-run panel database of annual county-level coal mining production, average value, and employment for the coal-producing counties in the United States from 1900 to 1976. These data provide measures of coal mining activity that vary across time and space, allowing me to provide a description of how coal production, prices, and technology changed in the

United States. The article also identifies the within-county net effects of price variation on county-level coal production decisions, after controlling for changes in technology and isolating variation in local prices due to changes in national equilibrium conditions.

The results provide evidence that county average values of coal produced do not increase or decrease as much as changes in national prices and transportation costs would predict, which means variation based only on national prices of coal and rail are not capturing the full variation in local prices. This leads me to believe there was a supply response happening at the local level to changes in national prices. The article also showed that when county average values of coal are used as the local price explanatory variable, along with controlling for the level of technology, the relationship with county production is negative and significant in fixed effects regressions. If local operators respond to increases in national price signals by increasing local production, this could have a negative effect on the average value of coal produced. If the response is large enough, the average value of coal produced could actually decrease. These negative results suggest this may have been occurring, and that supply side responses were dominating national shifts in equilibrium prices.

The effect of county average value in the IV regressions, done to address this endogeneity issue, is positive and implies increases in the average value of coal produced are associated with increases in the amount of coal produced within a county. The result is specific to within-county variation, the inclusion of state-by-decade interactions to control for changes in technology, and the isolation of the variation in local average values due only to changes in national and international equilibrium conditions. Increases in past local average values were shown to have had a negative effect on current year coal production, suggesting coal operators may have been aware of the past behavior of coal prices, and were responding to them at the local level. It also suggests there was a complex relationship between past, current, and future coal prices with operator behavior that deserves further attention.

The analysis also showed representing the opening and closing of mining operations by assuming "missing" counties without continuous reporting have no coal mining activity, has significant consequences to the analysis of prices, production, and technology. It suggests there was a very complicated relationship between the timing of national price conditions, local prices, and coal production for those marginal mining areas without continuous operations. The results also suggest there were some changes in the relationship between production, prices, and technology from 1900 to 1976. The rise of coal production mechanization and increase in productivity shown in Figure 3 could be a potential driver of these differences. This possibility could also be explored in future work.

The belief that economic actors respond to fluctuations in input costs and output prices is central to the field of economics. There is also a belief that conservation and responsible use of non-renewable resources is required for the success of future generations. The results of this article provide evidence that coal producers responded in a significant way to variation in national and local coal prices, and that coal producers were aware of, and responded at the local level to, the behavior of past coal prices. Understanding how non-renewable resource producers respond to fluctuations in input costs and output prices can help current and future policy makers analyze policies or initiatives that impact non-renewable and renewable resource markets.

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