Coase in the Coal Fields?

Historical Property Institutions in Appalachia and Long-Run Development

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Abstract

The Coase Theorem suggests that the initial assignment of property rights should not affect resource allocations if property rights are clearly defined and transaction costs are sufficiently low. In this paper, I test a natural application of the Coase Theorem in the Appalachian coal fields of the eastern United States, where a technological shock led to variation in the court-assigned property rights of surface property owners and mineral owners. I use a spatial regression discontinuity design across state borders to study whether the initial court assignment of property rights affected technology adoption, resource allocations, and long-run socioeconomic outcomes in the region. I find that weaker surface property rights led to 3.5 times greater exposure to surface mining and higher levels of historical coal production, despite similarity in the underlying coal characteristics. In the long-run, I find that weaker surface property rights led to 31% lower residential property values today—decades after the legal variation in property rights assignments were overturned. These results suggest that even temporary shocks to property rights institutions can have negative impacts on long-run outcomes.

Keywords: Appalachia, property rights, mineral rights, Coase theorem, coal, surface mining, regional development, property values

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> *Of course, if market transactions were costless, all that matters (questions of equity apart) is that the rights of the various parties should be well-defined and the results of legal actions easy to forecast. But as we have seen, the situation is quite different when market transactions are so costly as to make it difficult to change the arrangement of rights established by the law. In such cases, the courts directly influence economic activity.* (Coase, 1960)

1 Introduction

Institutions are one of the primary forces that drive economic development (North, 1991; Acemoglu et al., 2001; Besley and Persson, 2009; Dell et al., 2018). Property rights institutions are particularly important, because they determine who controls primary factors of production, like land and natural resources, and the investment incentives that drive economic activity (Besley, 1995; Alston et al., 1996; Field, 2007; Goldstein and Udry, 2008; Galiani and Schargrodsky, 2010; Goldstein et al., 2018; Behrer et al., 2021).

While property rights in developing contexts are often incomplete or weakly enforced, we generally think of property rights in the United States as being well defined and supported by other strong institutions that are necessary to enforce established property rights. However, technological advancements can create new externalities and change how existing delineations of property rights are exercised (Hornbeck, 2010; Gibbons et al., 2021). Where property interests are at odds with one another, the Coase Theorem suggests that bargaining with clearly defined property rights can achieve an efficient allocation of resources as long as transaction costs are sufficiently low (Coase, 1960). But there are many reasons—high transaction costs, imperfect competition, asymmetric information, etc.—why we would not expect the Coase Theorem to hold in practice, even in more favorable contexts like the United States.[1]

In this paper, I examine a natural application of the Coase Theorem in the Appalachian coal fields of the eastern United States, where a technological shock led to temporary, his-

[1] See (Zerbe, 2000) for an extensive discussion of the relevant literature.

torical variation in court-assigned property rights of surface and mineral owners. Horizontal severance deeds, which are common in the region, separate a property into two legally independent estates: a surface estate and a subsurface or mineral estate. The surface owner maintains property rights over the use of the surface and the returns from any agricultural or structural investment, while the mineral owner is granted ownership of the subsurface materials and limited easements of the surface property for the purposes of accessing their minerals. Technological advancements in the 1940s made surface mining, or "strip mining," a cheaper and more productive method of mineral extraction. However, because surface mining uses heavy machinery to completely remove all topsoil above the coal seams, the new technology caused significant damage to the surface property and imposed a negative externality on the surface owner that previous mining technologies did not.

The introduction of surface mining created ambiguity as to whether mineral owners had the inherent right to use this new technology or whether surface owners could prohibit the use of surface mining in light of the damage it inflicted on the surface property. This uncertainty led to litigation in state courts. Ultimately, these court decisions established the initial allocation of property rights in those cases and set a legal precedent in those states for similar cases moving forward.[2] Throughout the paper, I refer to states where surface owners could not exclude mineral owners from using surface mining as having weaker surface property rights relative to states where surface owners maintained these exclusion rights. In states with historically weaker surface property rights, mineral owners were found to have an inherent right to use surface mining and were not required to gain the consent of the surface owner or pay damages under normal use of surface mining techniques. However, if transaction costs are sufficiently low to allow agents to bargain, the Coase Theorem suggests that court decisions to assign initial property rights and liability should have no effect on resource allocations, because property holders can make Pareto-improving transactions to

[2]Here and throughout the rest of the paper, I use the term "legal precedent" to describe the court decisions arising from these cases; these rulings would be used to help determine rulings in similar cases in those states in subsequent years. While established legal precedents are not absolutely binding in future cases, they do establish a standard by which subsequent cases will be judged.

reach productive efficiency regardless of the initial assignment of rights. If the Coase Theorem were to hold in this context, we should see a convergence of resource allocations so that there is little difference in the extent of surface mining or coal production across areas with different property rights.

To examine whether historically weaker surface property rights affected the adoption of surface mining technology, resource allocation, and long-run property values, I use a spatial regression discontinuity design to compare observational units just inside the borders of states where the legal precedent weakened surface owners' property rights with observational units just outside these borders. Since court decisions only applied to horizontally severed estates in the coal fields, the analysis is restricted to treatment state borders within the coal fields.

Using 2024 geospatial data from the Office of Surface Mining and Reclamation Enforcement (OSMRE) and state-level geological surveys on the extent of past and current surface mining, I find that historical variation in court-assigned property rights did affect the adoption of surface mining technology and resource allocations in Appalachia. The proportion of land that was surface mined is 7.9 percentage points higher—or about 3.5 times greater—in states with historically weaker surface property rights where surface mining was permitted without the consent of the surface property owner. Furthermore, I digitized archival data from the United States Geological Survey (USGS) on yearly, county-level coal production from 1945 to 1997 to measure the effect of historically weaker surface property rights on resource extraction. I use a two-way fixed-effects specification to show that yearly coal production was higher by approximately 45,000 short tons per square mile of coal field in states with weaker surface property rights. Taken together, these "first stage" results indicate that historical differences in property rights affected the extent to which surface mining was used and the allocation of land for mining versus residential or recreational purposes, implying that the Coase Theorem (perhaps predictably) did not hold in this setting.

Legal precedents in states with weaker surface property rights were eventually overturned so that surface mining was no longer permitted on horizontally severed estates without the

consent of the surface owner, so it is unclear *ex ante* whether this historical variation in local property institutions might have persistent effects on economic outcomes in the region. A growing literature suggests that historical shocks can have persistent effects on long-run outcomes (Nunn, 2007; Bleakley and Lin, 2012; Allen and Donaldson, 2022). On the other hand, there is also evidence that the fundamentals of a place may be more important than historical shocks, which implies that outcomes may converge once the shock has ended (Davis and Weinstein, 2002). I further leverage this unique context to test whether a temporary shock to surface property rights affected long-run outcomes in Appalachia. Using property-level market values of residential properties in 2022 from CoreLogic in a spatial regression discontinuity, I find that exposure to the historical shock to surface property rights has had a persistent negative effect on modern property values. Residential property values are approximately 31% lower in states with historically weaker surface property rights than property values just across the border in states where surface owners maintained their exclusion rights. These results imply that negative effects associated with even temporary exposure to weaker property rights can persist decades after the property institutions have changed.

Because property values are directly linked to local property tax revenues, I use contemporary data on county-level property tax revenues in a spatial regression discontinuity design to examine whether lower property values may have had subsequent effects on local public finances. Counties in states in which surface owners could not exclude mineral owners from using surface mining have approximately $6.5 million less in yearly property tax revenues than nearby counties in comparison states (not statistically significant). Because property tax revenues are largely used to fund local public education, I also examined county-level expenditures on education. These results suggest that counties in states with historically weaker surface property rights spend approximately $12.9 million less per year, or about 65% less, in educational expenditures than counties just across the border (not statistically significant). These results provide suggestive evidence that significantly lower property values in states with historically weaker surface property rights may have contributed to lower

property tax revenues and expenditures on local public education.

To support the validity of a spatial regression discontinuity design in this context, I show that the characteristics of the underlying coal resources are continuous across the treatment state borders, implying that the results are not driven by discontinuities in geology at the borders that affect the suitability for surface mining. I also demonstrate continuity in net migration rates across the borders, which alleviates concerns that households self-selected just outside states with weaker surface property rights. Furthermore, because multiple state-level policies change as you cross state borders, I present falsification tests of the main outcomes across non-coal segments of state borders to show that the effects observed in coal areas are not simply the result of state-level policy differences.

This paper contributes to a growing empirical literature testing the implications of the Coase Theorem and the extent to which bargaining can achieve efficient allocations of resources in different contexts (Friedberg, 1998; Wolfers, 2006; Hornbeck, 2010; Bleakley and Ferrie, 2014; Behrer et al., 2021). Unlike most of this literature, which exploits variation in transaction costs, I use variation in the actual legal assignment of property rights as a natural test of the implications of the Coase Theorem (Akee, 2009; Bleakley and Ferrie, 2014; Leonard and Parker, 2021). This paper demonstrates that the initial assignment of property rights in this context significantly affected resource allocation and technology adoption (Akee, 2009; Hornbeck, 2010; Bleakley and Ferrie, 2014; Leonard and Parker, 2021). Bleakley and Ferrie (2014) suggest that the Coase Theorem may hold in the very long run, so that inefficiencies caused by the initial misallocation of land are resolved over time. I contribute nuance to this finding by examining a context with irreversibility, in which the original state of the land cannot fully be restored after it has been allocated to a particular use (Fisher et al., 1972; Arrow and Fisher, 1974). Consequently, counter to the conclusion in Bleakley and Ferrie (2014), I show that initial misallocations of land resources in the face of irreversibility are unlikely to be resolved over time.

This paper contributes to the literature on the legacy effects of institutions by provid-

ing empirical evidence of persistent effects associated with historical variation in property rights—an institution that has been relatively understudied in this literature (Acemoglu et al., 2001; Dell, 2010; Dell et al., 2018; Dell and Olken, 2020; Bazzi et al., 2020; Lowes and Montero, 2021). Many papers on the persistent effects of historical institutions are unable to isolate the specific institutions that drive results and attribute the effects to a bundle of weak institutions (Lee and Schultz, 2011; Grosfeld and Zhuravskaya, 2015; Lowes and Montero, 2021).[3] This paper isolates the effect of a historical shock to property institutions by leveraging a unique context in which variation in property rights existed for a period of time in which other important and often interconnected institutions—like state capacity to enforce property rights, democratic political processes, and the rule of law—were not affected.

Finally, this paper contributes to an extensive literature that debates the existence and determinants of a "natural resource curse" (Sachs and Warner, 1999). Papers in this literature often test the existence of a resource curse by exploiting variation in natural resource endowments at a more local level, in which they generally assume that institutions are common between their comparison groups (Papyrakis and Gerlagh, 2007; Michaels, 2011). This paper presents a complementary analysis by doing the opposite: examining long-term outcomes in areas with similar resource endowments but markedly different institutions. This paper illustrates that areas with a similar abundance of natural resources can experience significantly different paths of extraction and long-run outcomes based on the institutions that govern local resource extraction. This supports other work that suggests the institutions that govern natural resource extraction are of first-order importance when considering divergence in long-run outcomes (Sokoloff and Engerman, 2000; Mehlum et al., 2006; Borge et al., 2015). This paper also provides a cautionary note to practitioners in this literature that the frequent assumption that institutions are similar in areas that are geographically "close" could be a strong assumption that requires an in-depth analysis of any historical variations in institutions in addition to the structure of institutions during the study period.

[3]Papers that isolate the effects of specific institutions have examined forced labor arrangements (Dell, 2010; Dell and Olken, 2020) and local governance (Dell et al., 2018).

2 Background and Historical Context

2.1 Coal in Appalachia

The Appalachian region is located in the eastern United States and consists of a subset of counties in the following thirteen states: Alabama, Georgia, Kentucky, Maryland, Mississippi, New York, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, and West Virginia.[4] Figure 1 shows the states that the Appalachian Regional Commission considers to be part of Appalachia. For the purposes of this paper, I refer to the thirteen states mentioned above as Appalachia. Coal production was first documented in Appalachia as early as 1768 (Lasson, 1972). While the location of the major coal fields was established before the turn of the nineteenth century, the extraction technology and transportation infrastructure were not in place for any degree of commercial mining practices until the mid 1800s when the railroads breached the rough terrain of central Appalachia and underground mining replaced quarrying as the predominant form of coal extraction (Lasson, 1972; Zipper et al., 2021). From then on, there was a relatively steady demand for coal to heat homes, fuel coal-powered electrical plants, power locomotives, and support the burgeoning steel industry. Figure 2 shows the geographical extents of the coal fields in the United States as they were known near the turn of the twentieth century.

Appalachia was responsible for 80 percent of all the coal produced in the U.S. in 1930 and remained the top coal producing region in the United States until the 1970s (Davis, 2002; Zipper et al., 2021). To date, over 45 billion tons of coal have been extracted from the region, which is more than half of the U.S. cumulative coal production (Zipper, 2021).

[4]West Virginia is the only state which is entirely located in the region designated as Appalachia by the Appalachian Regional Commission.

2.2 Horizontal Severance Deeds

The period from the mid 1800s to the early 1900s saw the proliferation of horizontal severance deeds in Appalachia. Horizontal severance deeds created what are known as "split estates", where the property rights to the surface property and the minerals are owned by separate parties. A horizontal severance deed allowed the mineral rights to be acquired without the outright purchase of the land. Most of the original signers of these severance deeds were individuals who traveled the newly accessible interior of the Appalachian region specifically to acquire mineral rights, some on behalf of coal companies and others for their own interests (Appalachian Land Ownership Task Force, 1983; Caudill, 1963). Horizontally severed, or "split", estates are extremely common in the coal fields of Kentucky, Pennsylvania, West Virginia, Ohio, Tennessee, and other Appalachian states (Withrow, 1971). In fact, some reports suggest that the mineral rights for up to 90% of the land in some counties in eastern Kentucky were severed from the surface property in this manner (Withrow, 1971).

The original severance deeds gave mineral owners the rights to "all coal" and permitted them to use "whatever [methods] deemed necessary or convenient for mining purposes..." (Lang, 2015). Mineral rights acquired through these initial transactions were purchased for between $.50 to $5 per acre (Caudill, 1963). Most residents in rural Appalachia at this time were subsistence farmers who saw the sale of their mineral rights to be a favorable transaction; it allowed them to supplement their incomes with the sale of minerals that might not be mined for decades (Caudill, 1963; Lang, 2015). Over time, these mineral rights were either purchased outright by mining companies or leased to them from mineral owners who were then compensated some dollar amount for each ton of coal produced from their mineral estate. Either through direct purchase of the land or through the purchase of severed mineral rights, an estimated 85% of the minerals in Appalachian states are estimated to be owned by nonresidents (Caudill, 1963).

2.3 Technological Change and Subsequent Litigation

Underground mining was the predominant method of coal mining during the time that most severance deeds were signed in Appalachia. Underground mining during this period mostly consisted of block and pillar mining wherein miners would dig a shaft down to the coal bed and proceed to mine the coal seam, removing the coal by transporting it to the surface via the mining shaft. In order to keep the ceiling of the mines from collapsing, miners had to leave pillars of coal within the seam as support, which in turn supported the surface property, but which prohibited them from extracting all of the coal in a given seam.

While underground mining methods largely left the surface property unscathed, the same could not be said for surface mining techniques.[5] Technological advancements in the mid-1940s—the adoption of heavy machinery—enabled the large-scale production of coal via surface or "strip" mining. Because surface mining methods are faster and less labor intensive than traditional underground mining, the use of surface mining techniques became widespread in Appalachia as soon as the 1950s (Munn, 1975). Surface mining methods, including auger mining, contour mining, and mountaintop removal mining, among others, use heavy machinery to remove entire swaths of topsoil to access the coal underneath. These processes drastically change the contours of the surface property even under standard use of surface mining (see Figure 3). At least 2.5 million acres of the Appalachian coalfield has been affected by surface coal mining since the late 1970s, not including surface mining that occurred prior to the establishment of the Office of Surface Mining and Reclamation and Enforcement (OSMRE) (Zipper et al., 2021).

The development of surface mining technology resulted in litigation between mineral owners who wanted to use surface mining techniques to access their minerals and surface owners who sought to protect their properties.

[5]Typical alterations to the surface property to facilitate underground mining included building access roads and digging the mine shaft.

2.4 Historical Property Rights Institutions in Appalachia

The litigation between surface owners and mineral owners of severed estates resulted in variation in Appalachia's historical property institutions. State-level court decisions in some states allowed the destruction of the surface owner's property without their consent or compensation for damages by mineral owners wishing to use surface mining techniques. (See Appendix A for a more extensive discussion of the legal justifications of these court decisions.) These legal precedents should be viewed as a negative shock to surface property rights in that it effectively dissolved surface owners' exclusion rights to their properties.

Exclusion rights, or the ability to exclude other people from using your property for any purpose without your consent, are a fundamental component of the bundle of rights that constitute private property rights. In the most basic sense, the strength of one's property rights is directly proportional to the extent to which the owner's decision about how their property should or should not be used actually determines its use (Alchian and Demsetz, 1973). Court decisions in some states prevented the surface owner from excluding the mineral owner from destroying the surface property via surface mining. In other words, it weakened the property rights of the surface owner by removing the exclusion rights from the bundle of property rights they believed were inherent to their ownership of the surface and by removing a right which surface property owners in other states continued to exercise.

Kentucky and Pennsylvania were the two states whose courts determined that surface owners could not exclude mineral owners from using surface mining to access their minerals and that mineral owners were not liable for damages to the surface. The legal precedent held for eleven years in Pennsylvania from 1950 to 1961 and for thirty-seven years in Kentucky from 1956 to 1993. See Table 1 for details regarding the legal precedents that determined treatment status for the purposes of this paper.

3 Data Sources and Important Variable Definitions

3.1 Treatment Definition

I document the inception and duration of state-level legal precedent concerning how surface owners' rights were enforced for all coal states in Appalachia and their border states, including Alabama, Georgia, Kentucky, Illinois, Indiana, Maryland, Mississippi, Missouri, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia. This information was gathered from the historical court documents of cases pertaining to the enforcement of surface and mineral rights on horizontally severed estates in each state. Table 1 provides additional details on the treatment status of each state, the duration for which the legal precedent held in that state, and the case references associated with the court decisions that determined treatment classification.

3.2 Mineral Resources and Production Data

This analysis incorporates the spatial coordinates for the geographic location of the coal field boundary as determined by the United States Geological Survey (East, 2021). Data on the location of the coal field boundary is used to classify whether an observational unit falls within a coal field.

I also utilize newly digitized archival data provided by the United States Geological Society (USGS) on historical coal production for the Appalachian and Illinois coal basins.[6] This data includes county-level coal production measured in thousands of short tons for each year from 1945-1997 in the Appalachian and Illinois coal basins. This data is used to check for balance on pretreatment coal production and to test whether coal production increased for treatment states during years in which the legal precedent weakened surface owners' property rights in those states.

[6]The Illinois coal basin includes the coal fields of Illinois, Indiana, western Kentucky, Missouri, and Tennessee.

I use the USGS National Coal Resources Data System UStratigraphic (USTRAT) database for records of underlying coal characteristics (U.S. Geological Survey, U.S. Geological Survey). The database provides stratigraphic descriptions from millions of point locations inside the U.S. coal fields. I restrict these points to drill holes and cores drawn from within the coal fields in my sample.[7] I also remove all coal resources that are not recoverable, either because they lie at such a depth that they are not economically feasible to mine even by today's standards or because the coal lies shallow enough that it would be weathered and unusable. I then use the remaining points and the descriptions of each geological seam located at each point to calculate geographic features of the coal fields at each point location. For example, I calculate overburden, the average thickness of coal seams, and total thickness of all coal seams located at each point.[8] I also calculate stripping ratios for each point, or the ratio of thickness of noncoal seams relative to coal seams. These variables are important because the amount of overburden and stripping ratios directly determine the profitability of mining a given coal seam.

For the estimates of the extent of surface mining, I use data from the Office of Surface Mining Reclamation and Enforcement (OSMRE) GeoMine database which provides shapefiles of the boundary locations of past and current surface mines (Office of Surface Mining and Reclaimation Enforcement, 2024). Where OSMRE data was missing or incomplete, I use data from individual state's geological surveys on the extent of surface mining in that state.[9]

[7] I was advised from a contact within the USGS that drill holes and cores are the most reliable point classifications to determine the geology of underlying coal resources. Other points might include data drawn directly from mining sites, including mining ventilation shafts, roadways, etc.

[8] Overburden is calculated as the total depth of non-coal seams before the first coal seam at each point.

[9] I use state geological survey data for Indiana, Ohio, and Pennsylvania since the state geological survey data was more complete than the OSMRE data for these states. OSMRE data are missing for Maryland and Missouri, and the shapefiles for the extent of surface mining in these states were not available at the time I contacted the state geological surveys. Therefore these states are currently missing in the analysis of the extent of surface mining, but will be incorporated once these shapefiles become available.

3.3 Data on Long-run Outcomes and Mechanisms

I use CoreLogic Property Basic files of 2022 property values to examine long-run effects on residential property values. The data reported are market value estimates as reported to CoreLogic by local government authorities. The data are reported as a total market value for each property; this figure is also subdivided as a land value and improvement value for each property. The data also includes the latitude and longitude associated with each property, which I use to classify whether a property lies within a coal field boundary and to calculate the euclidean distance of each property to the nearest treatment state's border. I restrict the properties to residential properties that are classified as single family residential properties.[10]

The Government Finance Database is a cleaned and consolidated version of the U.S. Census of Government data which I use for outcomes on local government revenues and expenditures, including property tax revenues and educational expenditures (Pierson, Hand, and Thompson, Pierson et al.). Data on county-level net migration patterns from 1950-2010 come from the Applied Population Laboratory at the University of Wisconsin-Madison (Egan-Robertson et al., 2024).

To examine whether historically weaker protections for surface property rights affected educational attainment, I use U.S. Census and American Community Survey data. Together, these sources create a time series of educational attainment outcomes measured as the share of the population over the age of 25 with less than 9th grade education, 9th grade to some college, or bachelors or higher. The data years range from 1970-2016.

The Statistics of Income (SOI) Division of the Internal Revenue Service (IRS) provides a zip code level dataset of the share of individual income tax returns filed with an income in specified bins of the income distribution. These data are for income tax returns filed for the 2021 tax year. I use this data to test for differences in current income distributions across the borders of states with historically weaker surface property rights.

[10]This would exclude some residential properties such as mobile homes, apartments, nursing homes, etc.

4 Empirical Strategy

I use a spatial regression discontinuity approach to compare observational units just outside and just inside the borders of states with historically weaker protections for surface property rights. I restrict the analysis to observational units within the coal field boundary because the historical legal precedent concerning whether surface owners could exclude mineral owners from using surface mining techniques only mattered inside the coal field boundary where there are horizontal severance deeds.[11]

4.1 Empirical Specification

I estimate the following regression equation for the spatial regression discontinuity:

$$Y_{cbs} = \alpha_0 + \beta_1 Treatment_s + \beta_2 Distance_{cb} + \beta_3 Treatment \times Distance_{cbs} + \gamma_b + \epsilon_{cbs} \quad (1)$$

Here, Y is the outcome for observational unit c , such as county, census tract, or block group, along boundary segment b in state s. $Treatment$ is an indicator variable if state s had historically weaker surface property rights. $Distance$ is the running variable and represents the Euclidean distance from the centroid of observational unit c in state s to the nearest point on a treatment state's border . Boundary segment fixed effects are denoted by γ_b. The main specification uses boundary segments that are divided by each state border pair. (See Figure 4 for a map of the boundary segments used as fixed effects in the main regression discontinuity specifications.) I cluster the standard errors at the state level because that is the level at which the legal precedent was decided and enforced. I use wild cluster bootstrap confidence intervals for inference to account for the small number of clusters in the main specifications (Cameron and Miller, 2015; MacKinnon and Webb, 2018; MacKinnon et al.,

[11]Due to data limitations on the share of land subject to severed ownership of the surface and mineral estates, I am unable to rely on any variation in the proliferation of severance deeds for my analysis.

2023). For the main specifications, I restrict the sample to observational units that are within the Calonico et al. (2014) optimal bandwidth for each outcome and use a first-order polynomial of euclidean distance to a treatment state's border and triangular kernel weights.

4.2 Discussion of Identification Assumptions

This section covers the identification assumptions that are required for the spatial regression discontinuity specification presented in the previous section to recover the causal effect of historical variations in surface property rights on outcomes of interest.

The primary identification assumption for the validity of regression discontinuity estimates is that potential outcomes are continuous at the cutoff, or, in this case, the boundary that forms the spatial discontinuity. This requires that any covariates that could potentially affect the outcome change smoothly at the border so that only the treatment status "jumps" at the border. Some important potential confounders would be geological variables that determine the suitability for surface mining, such as elevation or the characteristics of the underlying coal resources. Table 2 shows the results of continuity checks of important coal field characteristics as reported in borehole data from the USGS USTRAT database. The regression discontinuity results show that there is no significant difference in overburden, elevation, stripping ratios, the average thickness of coal seams, the total thickness of coal seams, or the number of coal seams as you cross the state borders between treatment and control states. The continuity of the underlying coal characteristics across state borders implies that, at least near the borders, the coal fields were similar and similarly suitable for surface mining.

Furthermore, since the spatial discontinuity that I exploit is an administrative boundary, the implicit assumption is that the many other policies that change at treatment state borders are not driving any differences in outcomes we observe(Keele and Titiunik, 2015). I use a regression discontinuity of the main outcome variables along the state borders in noncoal areas as falsification tests to show support for this assumption in Section 5.5.

Another important identification assumption in regression discontinuity designs is that there is no manipulation of the running variable; that is, that there is no evidence of differential sorting across the threshold. In spatial regression discontinuities, the primary concern is sorting across the relevant boundary. In this setting, the land cannot be moved across the boundary. However, one might still be concerned that individuals may have sorted to either side of a treatment state border and that, if this occurs, some of the long-run impacts on socioeconomic outcomes that we observe could be driven by differential migration. To help alleviate these concerns, I examine county-level net migration rates by decade from 1950-2010. Figure 7 shows that there is no statistically significant difference in net migration across treatment state borders during the sample period. However, there is significant net out migration from all coal areas in the sample for most decades, so there is still a potential identification concern if the historical variation in property rights induced differential migration from certain demographic groups, such as higher income or higher education individuals, from treatment states to control states or vice versa.

An established literature suggests that institutional development may be driven endogenously by the characteristics of a place so that the institutions that eventually arise entrench advantages for the elite or maximize resource extraction (Sokoloff and Engerman, 2000; Acemoglu et al., 2001). A final potential threat to identification in this setting is that the change in property rights institutions was endogenous. For instance, the primary concern in this setting is that the states with the most plentiful or valuable coal reserves or the states with higher initial levels of coal production were the states that eventually established legal precedents that facilitated access to these minerals. Then, the estimates would not be causal and would be partially driven by the endogenous selection into institutions. This concern is somewhat alleviated in this context because the property right institutions in question were established by court judges rather than policymakers, who one might argue are making decisions on the legal merit of cases rather than trying to stimulate economic activity. However, to address the concern that states endogenously selected into treatment, I use historical

data on coal production to test whether treatment states had higher levels of coal production prior to treatment. Table 3 shows that there were no statistically different levels or change in coal production in the pretreatment period for both states from 1945-1949.[12] However, the magnitudes of these estimates are large, so I cannot completely rule out the possibility of endogenous state-level selection into treatment.

4.3 Alternative Empirical Specification

I employ an alternative two-way fixed effects specification for some outcomes with a panel data structure as outlined below:

$$Y_{cst} = \alpha_0 + \beta_1 Treatment_{st} + \phi_c + \theta_t + \epsilon_{cst} \tag{2}$$

Here, Y is the outcome for county c in state s at time t. $Treatment$ is an indicator variable if state s had relatively weaker surface property rights in time t.[13] Fixed effects for the county and year are represented by ϕ_c and θ_t, respectively. I cluster the standard errors at the state level because that is the level at which the legal precedent was decided and enforced. I use wild cluster bootstrap confidence intervals for inference to account for the small number of clusters in the main specifications (Cameron and Miller, 2015; MacKinnon and Webb, 2018; MacKinnon et al., 2023).

[12] I prefer the TWFE specification for these outcomes because year fixed effects allow me to control for common aggregate variations in coal production. The specification used for these estimates is identical to 2 except that Treatment is a state-level indicator whether a state will eventually be subject to legal precedents that weak surface property rights. There are also no county fixed effects for these estimates. While this is my preferred specification, Figure 15 shows the spatial regression discontinuity estimates by year for 1945-1949. While the estimates are not statistically significant, they are large in magnitude in this specification as well.

[13] This specification is primarily used for historical coal production estimates that benefit from controlling for year fixed effects to absorb aggregate variation in coal production. Other outcomes that would experience persistent effects from treatment even after the legal precedents have been overturned, such as property values or property tax revenues, are not suitable for this specification because destruction of properties during the treatment period would affect these outcomes even after the legal precedents determining treatment have been overturned.

5 Results

5.1 Technology Adoption and Resource Allocation

According to the Coase theorem, as long as property rights were clearly defined, the court determination of whether the mineral owner could use surface mining or whether the surface owner could exclude mineral owners from using surface mining techniques should not have affected the eventual allocation of resources. In other words, if the Coase theorem holds in this setting, we would not expect the extent of surface mining or total coal production to respond to the legal precedent. Under the Coase theorem, we would expect convergence on these outcomes because surface and mineral owners could bargain to reach the optimal allocation of resources regardless of the initial assignment of property rights by the courts.

Using current data from OSMRE and state geological surveys on the current and historical extent of surface mining, I test whether treatment states with historically weaker property rights for surface owners were differentially exposed to more surface mining. Figure 5 presents a map of past and current surface mines. To estimate whether surface mining was used more extensively in treatment states, I use a simple spatial regression discontinuity across treatment state borders. Figure 6 depicts a plot of the regression discontinuity and Table 4 reports that states with historically weaker protections for surface property rights were subject to significantly more surface mining than border states. Treatment states saw 7.9 percentage points more surface mining than nearby control states with similar suitability for surface mining; a difference of about 3.5 times the magnitude of exposure in states where surface owners were able to exclude mineral owners from using surface mining.

Using data on historical coal production before and after the legal precedent changed for different states in Appalachia, I use the alternative two-way fixed effects specification in Equation 2 to estimate whether coal production was markedly different in treatment states during the periods in which the legal precedents held.[14] Table 5 reports these results.

[14]I prefer this specification for this outcome because year fixed effects allow me to control for common aggregate variations in coal production, which increases power. However, I report the spatial regression

The magnitude of all outcomes in the table suggest that coal production was likely higher in counties in treatment states than counties in comparison states during the periods in which the legal precedents held.[15] While the coefficients are significant under conventional clustered standard errors, only the coefficient on coal production per square mile of coal field is significant under the wild cluster bootstrap procedure. Column 2 indicates that counties in treatment states produced approximately 45,000 short tons more coal per square mile of coal field than counties in comparison states.

Together, these results suggest that weaker protections for surface property rights resulted in more extensive adoption of surface mining as a production technology and increases in total coal production. These results also suggest that the initial assignment of property rights by the courts did affect resource allocation in this context. For example, there was a greater portion of land used for surface mining in treatment states as opposed to residential or recreational alternative uses as in nearby control states with similar underlying coal characteristics. This suggests that transaction costs were sufficient to prevent agents from bargaining to reach similar allocations of resources despite the initial assignment of rights.

5.2 Residential Property Values

Weaker property rights for surface owners almost certainly affected historical property values in treatment states while the legal precedents held. Surface owners may have had direct damage to their properties due to surface mining, or property values could have fallen due to an increased risk of property destruction. But what about property values today?

There are two primary channels through which the historical legal precedents could have affected contemporary property values: direct damage to the property and disincentivizing property investment by increasing the expectation of property destruction in the future.

discontinuity results in Figure 15 to show that on average the magnitude of the coefficients are similar to those recovered in the TWFE specification.

[15]While it is true that, although the difference is statistically insignificant, coal production was higher for treatment states prior to the legal precedents that changed the allocation of property rights, it is unlikely that these pretreatment differences alone explain these differences in coal production after the legal precedents were established.

The extractive legal precedent enabled mineral owners to use surface mining techniques to recover their minerals without the consent or payment of damages to surface owners for the destruction that surface mining necessarily causes to the surface property. In treatment states, this resulted in uncompensated damages inflicted upon the surface property, reducing property values for properties directly affected by surface mining and reducing the amenity value of properties located nearby. Furthermore, the fear of future property destruction would have disincentivized property investment in treatment states. The uncertainty of future property destruction would have reduced the incentives for surface owners to invest in their property, knowing that the property could be destroyed if the mineral owner chose to use surface mining techniques to access their minerals.[16]

I use CoreLogic property-level market value estimations to examine whether there is evidence that weaker property rights for surface owners and the increase in exposure to surface mining that weaker surface rights induced has had long-run impacts on property values today. Table 6 shows the results of spatial regression discontinuities of the market value of residential properties across treatment state borders. Column 1 shows the effect on total market values per acre, while Columns 2 and 3 show the total market value separated by land value per acre and improvement value per acre, respectively. These results indicate that property values drop significantly as one crosses the border into a state with historically weaker property rights for surface owners and that lower property investments seem to be the driving factor of the persistent difference in modern property values.[17] Overall, market values of residential properties are approximately 31% lower in treatment states relative to residential properties just across the border in control states.

I also check continuity of acreage, an important potential confounder of property values, across treatment state borders to ensure that these results are not explained by differences

[16]Because it was sometimes difficult to learn whether a given property had a severed mineral estate, this fear of future property destruction could also have extended to properties that were not necessarily part of a severed estate.

[17]Property improvement values are any improvements to the land value of the property. Improvements could include anything from building access roads or fences to building a structure, such as a home.

in parcel acreage across treatment state borders. Results are reported in Table 10. These results suggest that residential properties in treatment states may be slightly smaller than those just across the border in control states, but that these differences are not statistically significant and are likely not the primary factor driving these results.

5.3 Local Public Finances and Expenditures on Education

Property taxes play a critical role in the provision of local public goods. Property taxes constitute up to three-fourths of local government tax revenues (Lutz, 2008). Even accounting for intergovernmental revenue transfers, property tax revenue still accounts for up to a quarter of local government revenues (Lutz, 2008). Furthermore, property taxes assessed on residential properties are generally the largest component of property tax revenues. Property taxes from residential property made up 60% of the tax base for property taxes in 1991 (Lutz, 2008). Therefore, significant drops in residential property values could significantly reduce the amount of property tax revenue collected by localities. This would put strain on local public finances and, if intergovernmental transfers were not sufficient to counteract the shortfalls in revenue, could affect the provision of local public goods.

The previous section discusses the finding that property values drop significantly as one crosses a border into a treatment state within a coal field, even decades after the historical variation in surface property rights were overturned. Although data limitations prevent me from showing the evolution of property values in treatment states relative to control states over time, I now turn my attention to examining how negative shocks to property values may have affected local public finances and public good provision. In particular, I examine the effect of the historical variation in surface owners' property rights on property tax revenues and education expenditures using data from the U.S. Census of Governments.

Table 7 reports spatial regression discontinuity results of county-level property tax revenues.[18] Column 1 reports spatial regression discontinuity results over treatment state bor-

[18]I follow Dell (2010) in pooling data across multiple years and incorporating year fixed effects into the

ders inside the coal field while Column 2 reports results over non-coal segments of the treatment state borders. While insignificant, these results suggest that treatment states may have had lower property tax revenues overall, but that the magnitude of this drop in property values was greater across the segments of the treatment state borders within the coal fields. These results suggest that inside the coal field, counties received approximately $6.5 million less in property tax revenues than coal counties just across the border in comparison states.

Local property taxes play an important role in financing local public schools(Kenyon and Reschovsky, 2014; Kenyon and Munteanu, 2021). In 2019, approximately 36% of public education revenue came from local property taxes (Kenyon, Kenyon). Table 8 reports spatial regression discontinuity results on county-level education expenditures across the coal and noncoal segments of treatment state borders. While these results are not statistically significant, they are suggestive that lower property values resulting from weaker protection for surface property rights may have had a detrimental effect on local property tax revenues and education expenditures in the coal areas of treatment states relative to nearby control states. Column 2 shows that we do not see this same negative effect on educational expenditures across noncoal segments of treatment state borders.

5.4 Educational Attainment and Income Distributions

In the previous sections, I present results that show significant reductions in property values for residential properties just across borders of states that had historically weaker protections for surface property rights. I also present suggestive evidence that the negative effects on property values may have translated to lower property tax revenues and educational expenditures.

In this section, I examine educational attainment and income distributions using spatial regression discontinuities across treatment state borders located inside the coal field boundaries. These are important dimensions to examine because existing research suggests that

spatial regression discontinuity. To account for this, I also use multi-way clustering for the standard errors in this specification at the state and year levels.

housing price shocks can have intergenerational effects on children's housing wealth and incomes (Daysal et al., 2023; Gilraine et al., 2023).

Using U.S. Census and American Community Survey time series data of the share of the population aged 25 and over with different levels of educational attainment, I compare the distribution of educational attainment across treatment state borders. Figure 8 shows significantly higher shares of the population with less than a 9th grade education in treatment states relative to control states. The effect size was approximately 5pp in 1970 and appears to attenuate toward little difference in outcomes in treatment relative to control states by 2016. However, the pattern shown in these results also appears in noncoal areas, which suggests that these differences in educational outcomes are likely driven by state-level differences in education policies or provision rather than a consequence of a significant shock to property values in coal areas. There are no statistically significant differences in the share of the population with 9th grade to some college and the share of the population with bachelor's degrees or higher in treatment states relative to control states.[19]

Finally, I use IRS zip code level data from the 2021 tax year to examine whether there are significant differences in the income distributions in treatment states relative to control states. The specified income bins are as follows: less than $25,000; $25,000-$50,000; $50,000-$75,000; $75,000-$100,000; $100,000-$200,000; and $200,000 plus.[20] Table 9 reports estimates of the differences in the share of returns filed in each income bin. Most coefficients are close to zero, meaning that there are little observed differences in the income distributions between treatment and control states. However, the results indicate that there is a significantly larger share of returns (1.6% greater) from zip codes inside treatment state borders that report incomes between $75,000-$100,000.

[19]These figures are reported and discussed in Appendix D.

[20]It is worth noting that, like the educational attainment groupings, these bins are fairly large and could be subsuming differences in income between treatment and control states.

5.5 Falsification Tests

As mentioned previously, an important identification assumption of spatial regression discontinuities is that no other confounder or policy that could affect the outcomes of interest changes discontinuously at the border. Because the spatial discontinuity in this context is an administrative border, this is a somewhat strong assumption since many policies change at state borders. Therefore, to provide evidence that other state-level policies are not driving the main results, I conduct falsification tests to examine the main outcomes across treatment state borders that lie outside of the coal fields. This is because the historical legal precedents that determined the strength of surface property rights relative to the property rights over subsurface minerals were only relevant in the coal fields. Therefore, if the same discontinuities in outcomes occur across noncoal segments of treatment state borders, this implies that another state-level policy is likely driving the results inside the coal fields as well.

Table 11 reports estimates spatial regression discontinuities of residential property values across noncoal segments of treatment state borders. These estimates are all positive and insignificant, suggesting that the pattern of lower property values that we observe as one crosses treatment state borders in coal areas are likely not attributable to state-level policies that apply to other parts of the state.[21]

While the outcomes reported for property tax revenues and expenditures on education in the previous section were not statistically significant, I still check whether the patterns we see in coal areas hold in noncoal areas as suggestive evidence of what could be driving the patterns we observe in the data. Figure 16 and 18 depict the evolution of property tax revenues and expenditures on education, respectively, across treatment state borders in noncoal areas. These figures show that the negative patterns in the data observed across treatment state borders inside the coal fields are not present. In fact, most coefficients

[21] However, the possibility still exists that other state-level policies that, like the historical legal precedents, only affect coal areas could still be contributing to the differences in property values we observe in treatment states relative to nearby control states.

are positive, particularly for educational expenditures. While only suggestive, these results imply that the negative trend we see in property tax revenues and educational expenditures in coal areas is likely not primarily driven by state-level policies. As mentioned in the previous section, the pattern of results for the distribution of educational attainment outcomes follows the same pattern in noncoal areas as in the coal fields, suggesting that state-level policies are likely driving the differences in educational attainment observed between treatment and control states.

Table 12 reports the spatial regression discontinuity estimates of the share of IRS tax returns for 2021 that were filed in each bin of the specified income distribution for zip codes near treatment state borders but outside the coal fields. There are no statistically significant differences in the share of returns filed in any of the income bins for zip codes in treatment states relative to zip codes just across the border in control states.

6 Discussion of Policy Implications

These findings have several important policy implications. First, they suggest that differences in institutional structures or enforcement of property rights could be an important and relatively understudied source of variation that may help explain persistent underdevelopment or regional socioeconomic disparities at a subnational level. Additional research into such regional variation in institutions is likely to be beneficial to policymakers aiming to stimulate regional economic activity. The results presented in this paper also have important policy implications for extractive industries in developing countries where existing delineations of property rights are often incomplete and industries where technological advancements create new ambiguities in established property rights. For example, one might consider how the persistent consequences of initial misallocation of resources might be relevant in the context of cobalt mining in the Democratic Republic of the Congo, deforestation in the Amazon, and many other potentially irreversible extractive activities in developing countries. If, as I show

in this paper, the initial allocation of property rights can have significant effects on the allocation of resources and persistent distributional effects in the United States, a setting that is likely the most charitable context for the Coase Theorem to hold, then we should expect that there will be significant barriers to bargaining in developing countries where property rights institutions are often weaker or not clearly defined. Therefore, because it is unlikely that we can rely on bargaining between private parties to reach an efficient allocation of resources in these contexts, it becomes increasingly important for governments and policymakers to clearly define and enforce property rights in these contexts. Especially in contexts in which resource extraction causes some irreversible damage to the environment, where the natural ecology cannot be restored (Fisher et al., 1972; Arrow and Fisher, 1974).

Furthermore, recent studies have shown that small earthquakes caused by hydraulic fracturing, or "fracking", activity, while small enough not to cause direct damage, significantly lowered property values by increasing residents' fear of future damage (Gibbons et al., 2021). This paper demonstrates that shocks to property values can show significant persistence even after the uncertainty about future property destruction has been removed. This research demonstrates that technological advancements can create new externalities that have persistent consequences for property owners even after the uncertainty about future property destruction has been removed. The stark difference in surface mining exposure and the persistent 31% lower residential property values in areas with weaker surface rights, even decades after legal precedents were overturned, highlight the critical importance of thoughtful property rights assignments where new production technologies are concerned or where liability for property damages may be unclear.

7 Conclusion

This work illustrates that institutions are of first-order importance in determining the extraction of natural resources and long-run differences in economic outcomes. This paper studies

a natural application of the Coase Theorem in the context of Appalachian coal fields by leveraging a technological shock and subsequent variation in court-assigned property rights. I find that the initial allocation of property rights between surface and mineral owners had significant and lasting impacts on resource allocations and long-run outcomes. States with weaker surface property rights experienced substantially higher levels of surface mining and historical coal production. These results support the point that Coase (1960) was trying to make: more often than not, the initial assignment of property rights will directly affect economic activity and the allocation of resources to different uses. More strikingly, these initial property rights assignments led to persistent economic consequences, with a significant and persistent drop in residential property values in states with historically weaker surface property rights.

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8 Figures



Figure 1: USA Coal Fields and Sample Region of Appalachian States

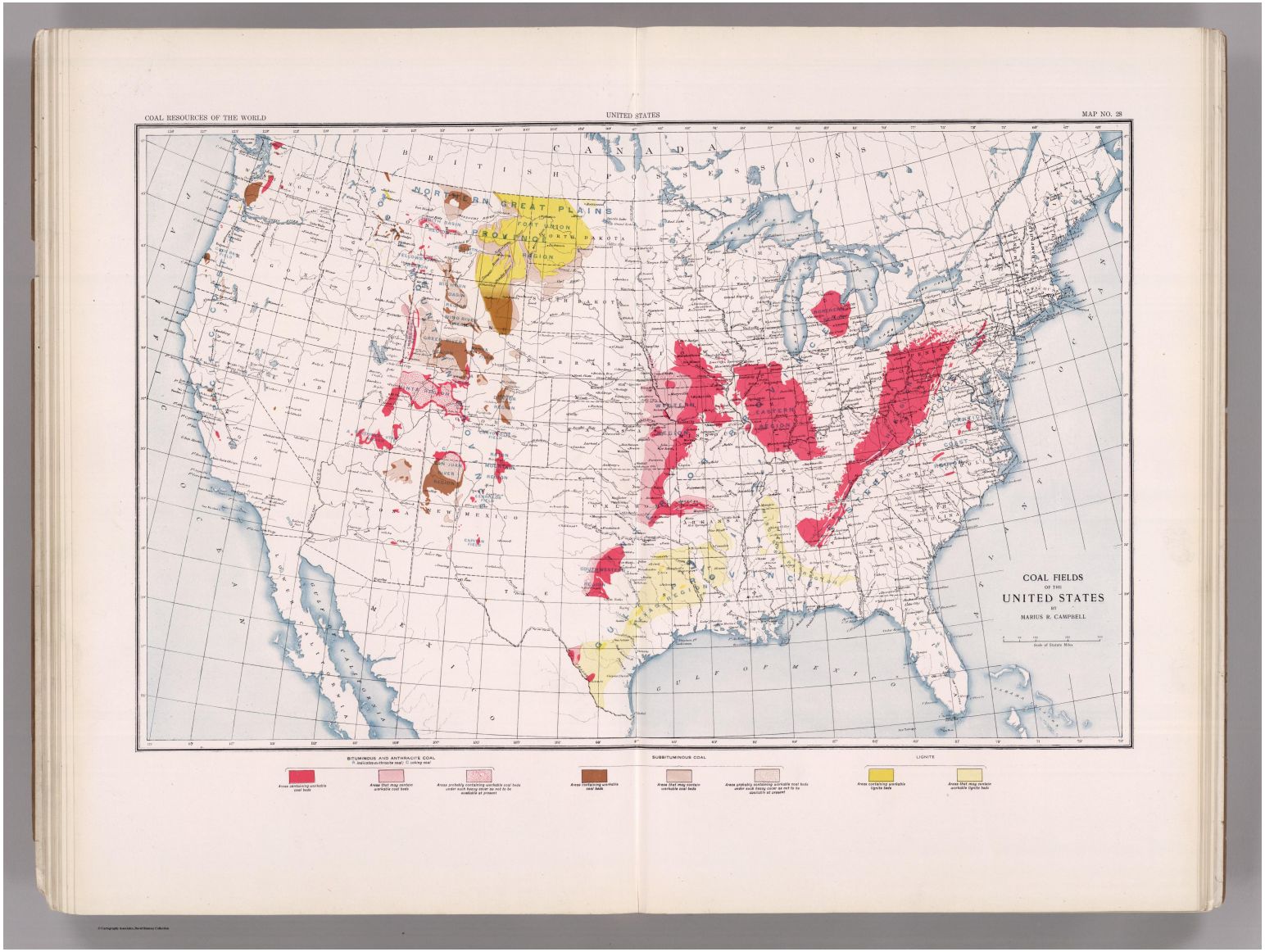


Figure 2: Historical Coal Map of the United States. (Campbell, 1913)



Figure 3: Photograph of a surface, or "strip," mining site near Barnesville, Ohio, in 1974.

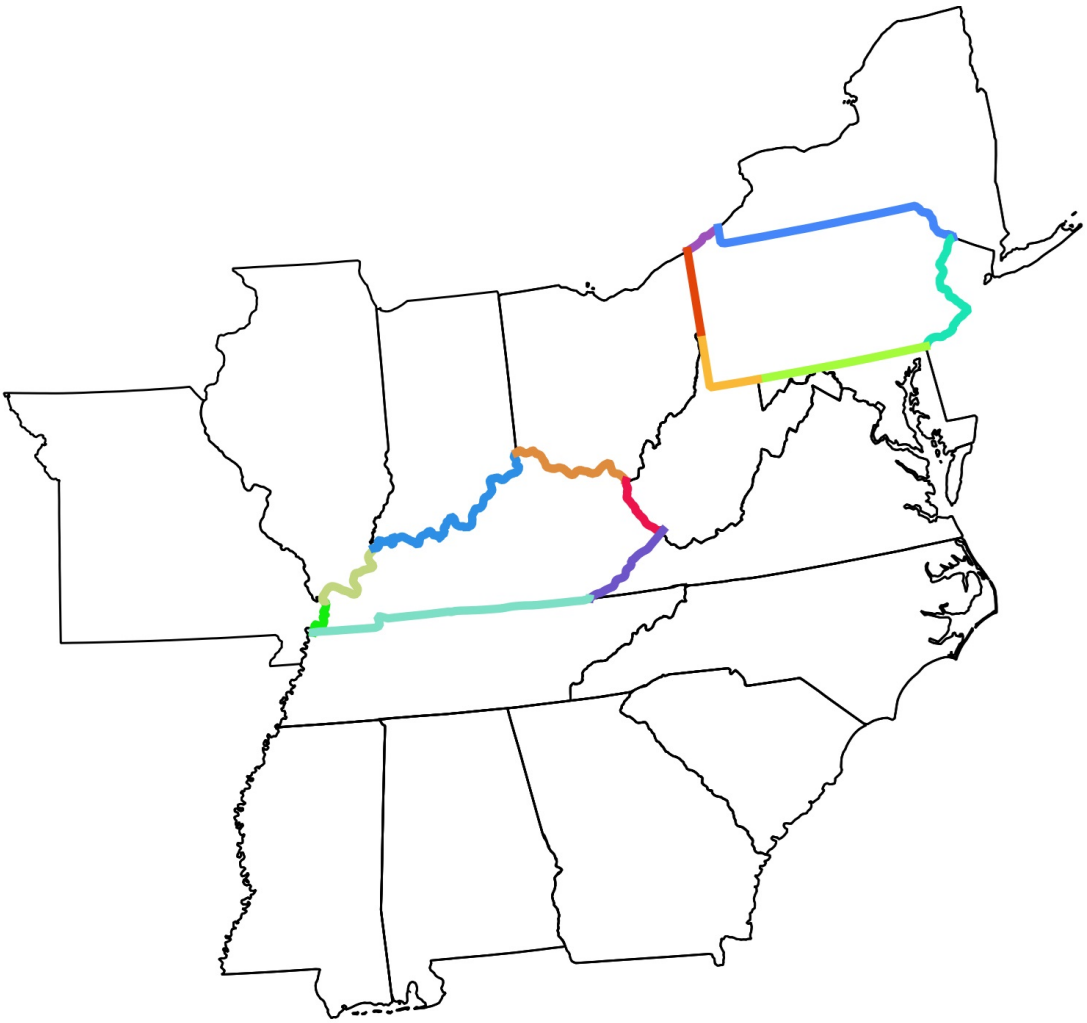


Figure 4: Map of treatment state boundary segments divided by state border pairs.

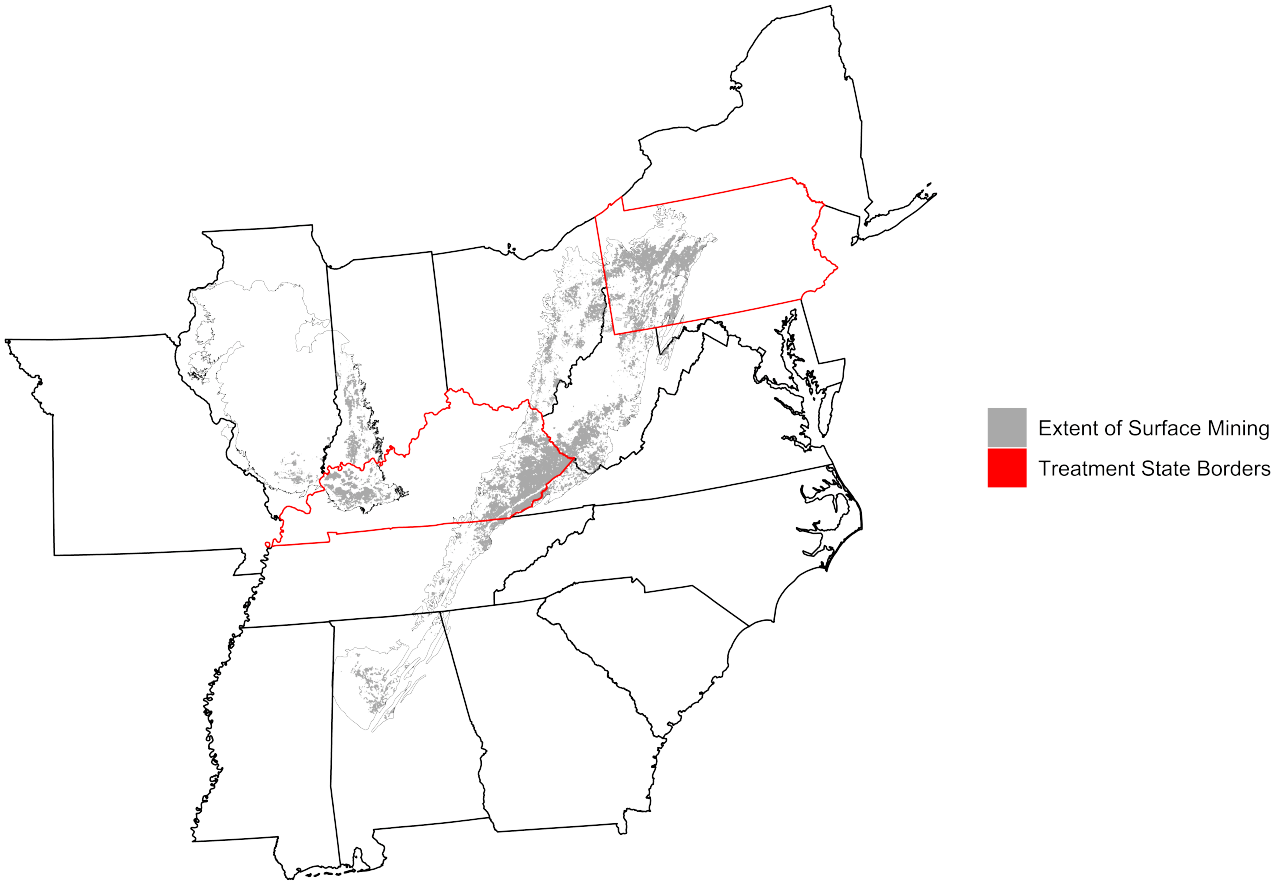
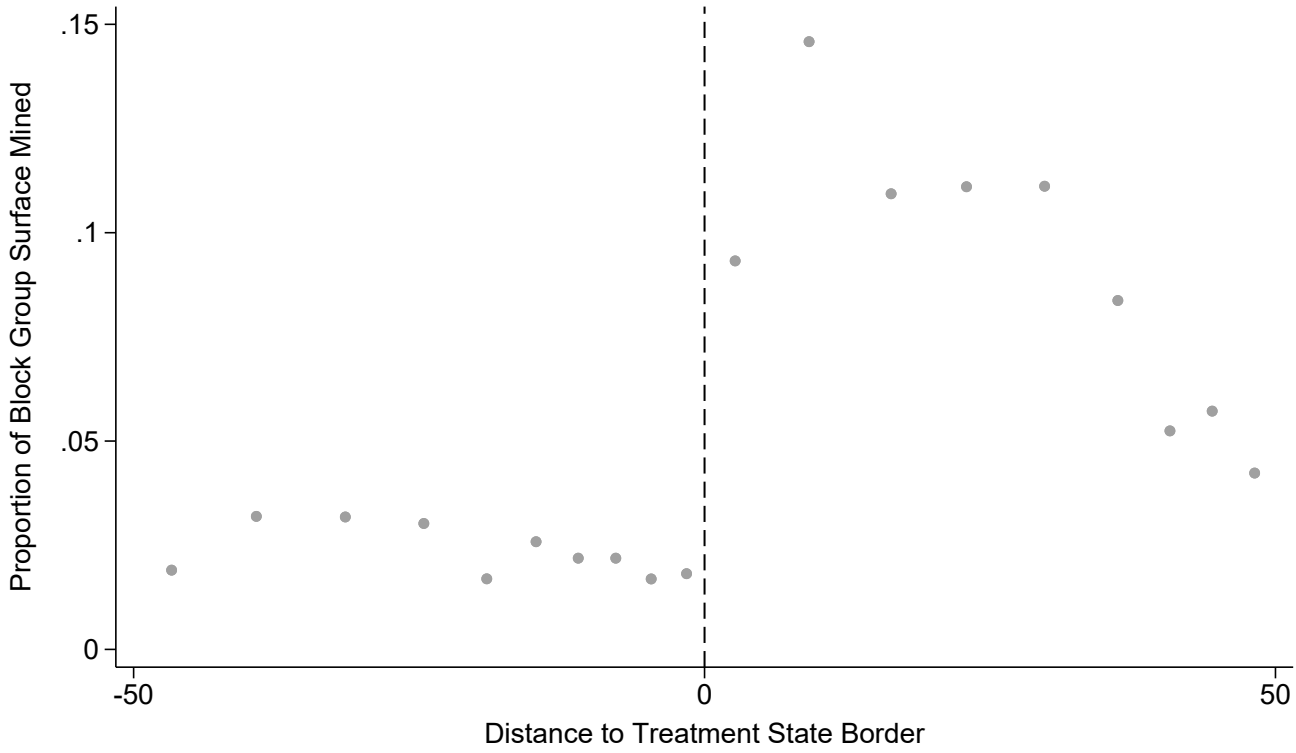


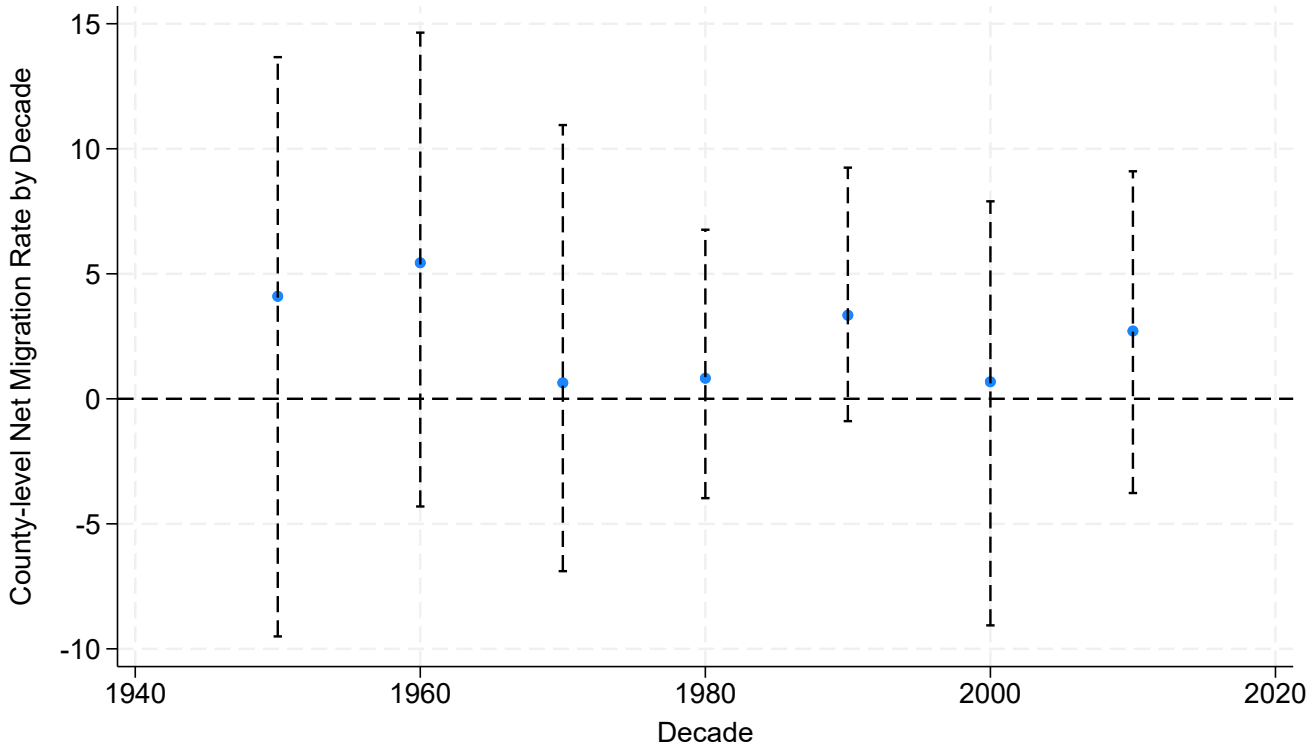
Figure 5: Map of past and current surface mining sites.

Figure 6: Spatial Regression Discontinuity Plot of the Extent of Surface Mining



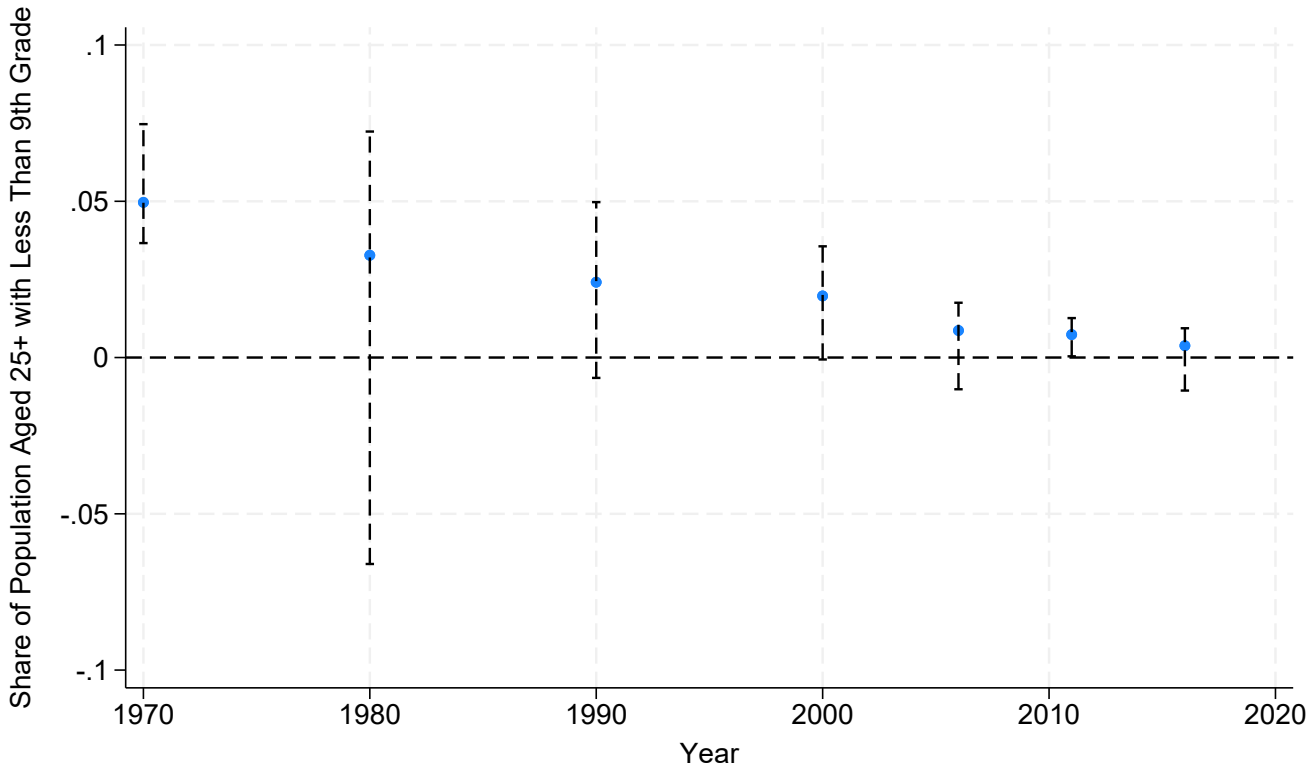
Notes: All distances are measured as the Euclidean distance of the centroid of each observational unit to the nearest point on a treatment state's border. Positive distances indicate observational units inside states with historically weaker surface property rights, while negative distances indicate observational units comparison states.

Figure 7: Continuity Check of County-level Net Migration Rate by Decade



Notes: Figure 7 shows spatial regression discontinuities of county-level net migration rates by decade across treatment state boundaries that lie inside the coal fields. All specifications use triangular kernels and state border fixed effects within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted.

Figure 8: Coal Areas: Spatial Regression Discontinuities of Educational Attainment (Less than 9th Grade)



Notes: Figure 8 shows spatial regression discontinuities of the share of the population 25 and over that have less than a 9th grade education in census tracts inside the coal field boundaries. All specifications use triangular kernels and state border fixed effects within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted.

9 Tables

Table 1: Treatment Definition

State	Weakened Surface Property Rights	Duration	Case References
Alabama	No	NA	
Georgia	No	NA	
Kentucky	Yes	1956-1993	Buchanan v. Watson 290 S.W.2d 40 (1956)
			Ward v. Harding 860 S.W.2d 280 (1993)
Illinois	No	NA	
Indiana	No	NA	
Maryland	No	NA	
Mississippi	No	NA	
Missouri	No	NA	
New York	No	NA	
North Carolina	No	NA	
Ohio	No	NA	Franklin v. Callicoat, 119 N.E.2cd 688 Ohio (1954)
Pennsylvania	Yes	1950-1961	Commonwealth v. Fisher 364 Pa. 422 (1950)
			Wilkes-Barre Township School Dist. v. Corgan 403 Pa. 383 (1961)
Tennessee	No	NA	Campbell v. Campbell, 199 S.W.2d 931 Tenn. (1946)
Virginia	No	NA	Phipps v. Leftwich, 216 Va. 706, 222 S.E.2d 536 Va (1976)
West Virginia	No	NA	Pittsburgh Coal Co. v. Strong, 42 S.E.2d 46 W. Va. (1947)

Notes: Table 1 indicates which Appalachian states and their border states ever established legal precedent that weakened surface property rights, the duration of time for which the legal precedent in each state held, and the important cases references that were used to determine treatment status for the purposes of this paper.

Table 2: Spatial Regression Discontinuity of Underlying Coal Characteristics

	(1) Overburden	(2) Elevation	(3) Stripping Ratio	(4) Average Seam Thickness	(5) Total Seam Thickness
Treatment	22.03	-89.73	1.375	-0.0694	1.987
	(17.69)	(75.05)	(2.457)	(0.147)	(1.579)
	[0.41]	[0.35]	[0.77]	[0.81]	[0.39]
Control Mean	125	1330	46	2	14
Fixed Effects	State Border Pairs	State Border Pairs	State Border Pairs	State Border Pairs	State Border Pairs
Observations	11,977	11,977	11,977	11,977	11,977
Bandwidth	32.9 km	32.9 km	32.9 km	32.9 km	32.9 km

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild-cluster bootstrapped pvalues are reported in brackets. These data come from the USGS USTRAT database and are measured at the borehole point level. The bandwidth used for these continuity checks is the Calonico et al. (2014) optimal bandwidth calculated for the main outcome on the extent of surface mining, which is reported in Table 4.

Table 3: Pre-treatment Coal Production

	(1) Total Coal Production	(2) Coal Production Per Square Mile of Coal Field	(3) ln(Coal Production Per Square Mile of Coal Field)
Future Treatment	1092.45	1.66	0.58
	(1571.6)	(3.198)	(0.685)
	[0.60]	[0.66]	[0.43]
Control Mean	1949.0	5.12	0.050
Year FE	Yes	Yes	Yes
Observations	1,069	1,067	1,067

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues are in brackets. Table 3 reports two-way fixed effects estimates of the differences in yearly, county-level coal production outcomes measured in thousands of short tons for treatment states before either state was treated (1945-1949) controlling for year fixed effects.

Table 4: Spatial Regression Discontinuity of the Extent of Surface Mining

	(1) Proportion Surface Mined
Treatment	0.0793** (0.0161) [0.02]
Control Mean	0.023
Fixed Effects	State Border Pairs
Observations	2,783
Optimal Bandwidth	32.9 km

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues are in brackets. Table 4 estimates how the proportion of a block group that has been surface mined changes as one crosses into a state with historically weaker surface property rights using a spatial regression discontinuity across state borders. The data come from the OSMRE or state-level geological surveys of the extent of past and current surface mines. The regression uses a triangular weighting kernel and boundary segment fixed effects for each state border pair. The bandwidth used is the Calonico et al. (2014) optimal bandwidth calculated for the outcome.

Table 5: Coal Production During Extractive Periods

	(1) Total Coal Production	(2) Coal Production Per Square Mile of Coal Field	(3) ln(Coal Production Per Square Mile of Coal Field)
Treatment	717.21 (127.8) [0.16]	45.26* (32.25) [0.07]	0.38 (0.0967) [0.17]
Control Mean	2446.6	62.9	62.9
Year Fixed Effects	Yes	Yes	Yes
County Fixed Effects	Yes	Yes	Yes
Observations	9931	9931	9931

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues are in brackets. Table 5 reports two-way fixed effects estimates of each outcome of coal production measured in thousands of short tons from 1945-1997 controlling for year and county fixed effects. Treatment is an indicator variable equal to one during the time periods when the legal precedent held that surface owners could not exclude mineral owners from using surface mining against their consent and zero otherwise.

Table 6: Coal Areas: Spatial Regression Discontinuity of Residential Property Values

	(1) Total Market Value Per Acre	(2) Land Value Per Acre	(3) Improvement Value Per Acre
Treatment	-174933*	-22918	-152016**
	(13672.2)	(5214.7)	(12367.5)
	[0.05]	[0.24]	[0.05]
Control Mean	566281	110857	455424
Fixed Effects	State Border Pairs	State Border Pairs	State Border Pairs
Observations	150,867	150,867	150,867
Bandwidth	4.76 km	4.76 km	4.76 km

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues and confidence intervals are in brackets. Table 6 reports spatial regression discontinuity results of residential property values across treatment state borders within the coal field boundary. The specification includes boundary segment fixed effects and triangular kernel weights. These data are 2022 market value estimations in U.S. dollars of residential properties from CoreLogic. The bandwidth used is the Calonico et al. (2014) optimal bandwidth for the total market value per acre. This bandwidth is used for all regressions in the table so that the properties included in the estimates are consistent across columns.

Table 7: Spatial Regression Discontinuity of Property Tax Revenues

	(1) Property Tax Revenue Coal	(2) Property Tax Revenue Non-Coal
Treatment	-6523	-4002
	(3614.1)	(30479.7)
	[0.20]	[0.93]
Control Mean	7182	43741
Boundary FE	State Border Pairs	State Border Pairs
Year FE	Yes	Yes
Observations	3395	2303
Optimal Bandwidth	32.28 km	33.23 km

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues are in brackets. Table 7 reports spatial regression discontinuity results of county-level property tax revenues across treatment state borders. Column 1 provides estimates across treatment state borders that lie within the coal fields, while Column 2 provides estimates across treatment state borders that lie outside the coal fields. The specification includes boundary segment fixed effects and triangular kernel weights. The bandwidth used is the Calonico et al. (2014) optimal bandwidth for each outcome.

Table 8: Spatial Regression Discontinuity of Education Expenditures

	(1) Education Expenditure Coal	(2) Education Expenditure Non-Coal
Treatment	-12975	24233
	(11206.8)	(47438.0)
	[0.38]	[0.71]
Control Mean	19708	84929
Boundary FE	State Border Pairs	State Border Pairs
Year FE	Yes	Yes
Observations	1091	1487
Optimal Bandwidth	28.97 km	48.25 km

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues and confidence intervals are in brackets. Table 8 reports spatial regression discontinuity results of county-level education expenditures across treatment state borders. Column 1 provides estimates across treatment state borders that lie within the coal fields, while Column 2 provides estimates across treatment state borders that lie outside the coal fields. The specification includes boundary segment fixed effects and triangular kernel weights. The bandwidth used is the Calonico et al. (2014) optimal bandwidth for each outcome.

Table 9: Coal Areas: Spatial Regression Discontinuity of Income Distribution Categories

	(1) Share of Returns <25k	(2) Share of Returns 25-50k	(3) Share of Returns 50-75k	(4) Share of Returns 75-100k	(5) Share of Returns 100-200k	(6) Share of Returns 200k+
Treatment	-0.00894	-0.000317	0.000461	0.0161**	-0.00470	-0.00264
	(0.00811)	(0.00337)	(0.00348)	(0.00553)	(0.00915)	(0.00394)
	[.4198]	[.9316]	[.9196]	[.0104]	[.6996]	[.5394]
Observations	986	986	986	986	986	986
R-squared	0.418	0.103	0.009	0.066	0.359	0.187
Mean	.35	.26	.16	.1	.12	.02
Fixed Effects	State Border Pairs	State Border Pairs	State Border Pairs	State Border Pairs	State Border Pairs	State Border Pairs
Bandwidth	50 km	50 km	50 km	50 km	50 km	50 km

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues and confidence intervals are in brackets. Table 9 reports spatial regression discontinuity results of the share of the population of each zip code that falls within the specified income ranges. The specification includes boundary segment fixed effects and triangular kernel weights within a 50km bandwidth around treatment state borders. These data are from 2022 IRS tax returns and is restricted to zip codes within the coal fields.

Table 10: Continuity Check of Acreage of Residential Properties

	(1) Acres
Treatment	-2.37 (2.425) [0.57]
Control Mean	1.38
Fixed Effects	State Border Pairs
Observations	348,303
Bandwidth	4.76 km

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues are in brackets. Table 10 reports spatial regression discontinuity results of acreage of residential properties within the coal field boundary. The specification includes boundary segment fixed effects and triangular kernel weights within the optimal bandwidth calculated for the main results on modern property values. These data are 2022 estimations of acreage from CoreLogic.

Appendices

A Legal Justifications for Different Court Decisions

Although the language of the severance deeds was similar across Appalachia, the courts of different states did not arrive at a similar interpretation of these deeds when there were disagreements about whether surface owners could exclude mineral owners from using surface mining techniques on their properties. The differences in legal precedent between states depended largely on whether the courts interpreted the deeds through the lens of property law or contract law.

The American legal system, like many former Commonwealth countries, is based on British common law. A property law precedent established in British common law is that mineral rights are dominant to surface rights in cases concerning severed mineral estates.[22] This precedent implied that the method of extraction chosen by mineral owners was of secondary importance to the fundamental right of ownership of the minerals (Colburn, 1979). Furthermore, these states ruled on the literal interpretation of the deeds that mineral owners had the right to use whatever mining method they deemed "necessary or convenient" and that mineral owners had the right to "all coal" which traditional underground mining techniques could not accomplish. States following the property law interpretation ruled that the mineral owners had the right to the temporary use of the surface property for the purposes of excavating the minerals by whatever method they chose to use, so long as that method was not specifically prohibited in the deed and did not cause destruction that was "arbitrary, wanton, or malicious" (noa, 1956). Ultimately the legal precedent in these states permitted surface mining without the consent of the surface owners or compensation for any damages to their property as it was prohibitively difficult in most cases for plaintiffs to show that normal use of surface mining techniques was "arbitrary, wanton, or malicious".

[22] This is due, in part, to the fact that the Crown was the established owner of mineral rights (Colburn, 1979).

Other state courts maintained the point of view that the severance deeds should not be interpreted through the lens of traditional property law but rather through the lens of contract law. Contract law emphasizes the intent of the parties at the time the contract or agreement was signed when adjudicating disagreements between the parties (Colburn, 1979). By this standard, state courts following a contract law interpretation focused on the mining methods that were standard during the time that the severance deeds were signed. They established that the original signing parties could not have granted the right to use a mining technology that was not in common commercial practice at the time that the deeds were signed (Colburn, 1979; Withrow, 1971). Therefore, since the right to strip mine was not specifically named or reasonably implied in the original severance deeds, mineral owners could only use surface mining to extract their minerals if they contracted with the surface owner for their permission to do so.

B Falsification Tests

B.1 Falsification Tests of Main Outcomes in Non-Coal Areas

Table 11: Non-coal Areas: Spatial Regression Discontinuity of Residential Property Values

	(1) Total Market Value Per Acre	(2) Land Value Per Acre	(3) Improvement Value Per Acre
Treatment	294637	3074	291558
	(127846.9)	(30203.9)	(124608.3)
	[0.23]	[0.94]	[0.23]
Control Mean	578128	113023	465105
Fixed Effects	State Border Pairs	State Border Pairs	State Border Pairs
Observations	284,132	284,132	284,132
Bandwidth	3.95 km	3.95 km	3.95 km

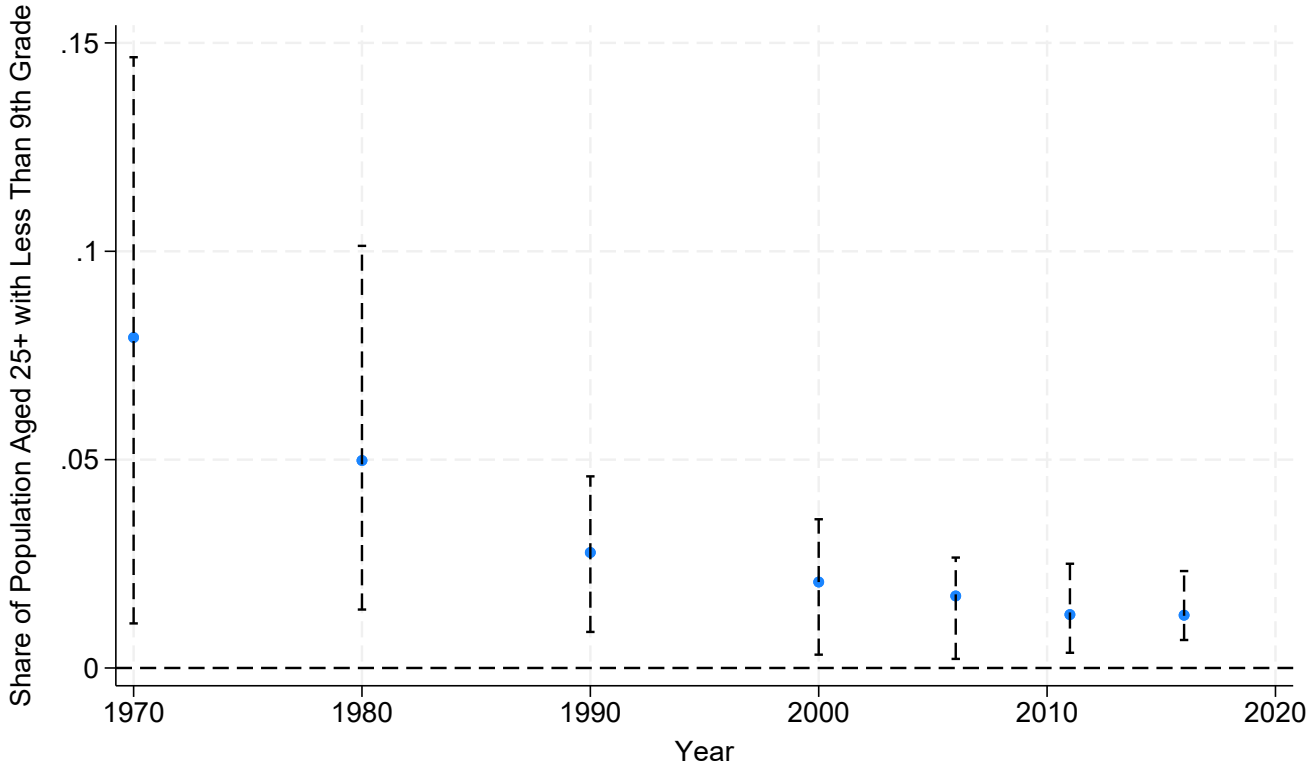
Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues are in brackets. Table 11 reports spatial regression discontinuity results of residential property values across treatment state borders that lie outside of the coal field boundary. The specification includes boundary segment fixed effects and triangular kernel weights. These data are 2022 market value estimations in U.S. dollars of residential properties from CoreLogic. The bandwidth used is the Calonico et al. (2014) optimal bandwidth for the total market value per acre. This bandwidth is used for all regressions in the table so that the properties included in the estimates are consistent across columns.

Table 12: Non-coal Areas: Spatial Regression Discontinuity of Income Distribution Categories

	(1) Share of Returns <25k	(2) Share of Returns 25-50k	(3) Share of Returns 50-75k	(4) Share of Returns 75-100k	(5) Share of Returns 100-200k	(6) Share of Returns 200k+
Treatment	0.00180	0.00335	-0.00419	-0.00126	-0.00653	0.00683
	(0.00958)	(0.00580)	(0.00439)	(0.00782)	(0.00904)	(0.00698)
	[.8738]	[.6288]	[.6794]	[.8998]	[.6122]	[.4860]
Observations	859	859	859	859	859	859
R-squared	0.179	0.142	0.039	0.068	0.228	0.111
Mean	.3	.24	.16	.1	.16	.05
Fixed Effects	State Border Pairs	State Border Pairs	State Border Pairs	State Border Pairs	State Border Pairs	State Border Pairs
Bandwidth	50 km	50 km	50 km	50 km	50 km	50 km

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues and confidence intervals are in brackets. Table 12 reports spatial regression discontinuity results of the share of the population of each zip code that falls within the specified income ranges. The specification includes boundary segment fixed effects and triangular kernel weights within a 50km bandwidth around treatment state borders. These data are from 2022 IRS tax returns and is restricted to zip codes outside the coal fields.

Figure 9: Non-coal Areas: Spatial Regression Discontinuities of Educational Attainment (Less than 9th Grade)



Notes: Figure 9 shows spatial regression discontinuities of the share of the population 25 and over that have less than a 9th grade education in census tracts inside the coal field boundaries. All specifications use triangular kernels and state border fixed effects within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted.

C Robustness Checks

C.1 Robustness of Main Results to Kernel Weights

Table 13: Spatial Regression Discontinuity of the Extent of Surface Mining

	(1) Proportion Surface Mined
Treatment	0.0881** (0.0169) [0.01]
Control Mean	0.022
Fixed Effects	State Border Pairs
Observations	2,466
Bandwidth	27.8 km
Kernel	Uniform Kernel

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues are in brackets. Table 13 estimates how the proportion of a block group that has been surface mined changes as one crosses into a state with historically weaker surface property rights using a spatial regression discontinuity across state borders. The data come from the OSMRE or state-level geological surveys of the extent of past and current surface mines. The regression uses a uniform weighting kernel and boundary segment fixed effects for each state border pair. The bandwidth used is the Calonico et al. (2014) optimal bandwidth calculated for the outcome.

Table 14: Spatial Regression Discontinuity of Residential Property Values in Coal Areas with Uniform Kernel

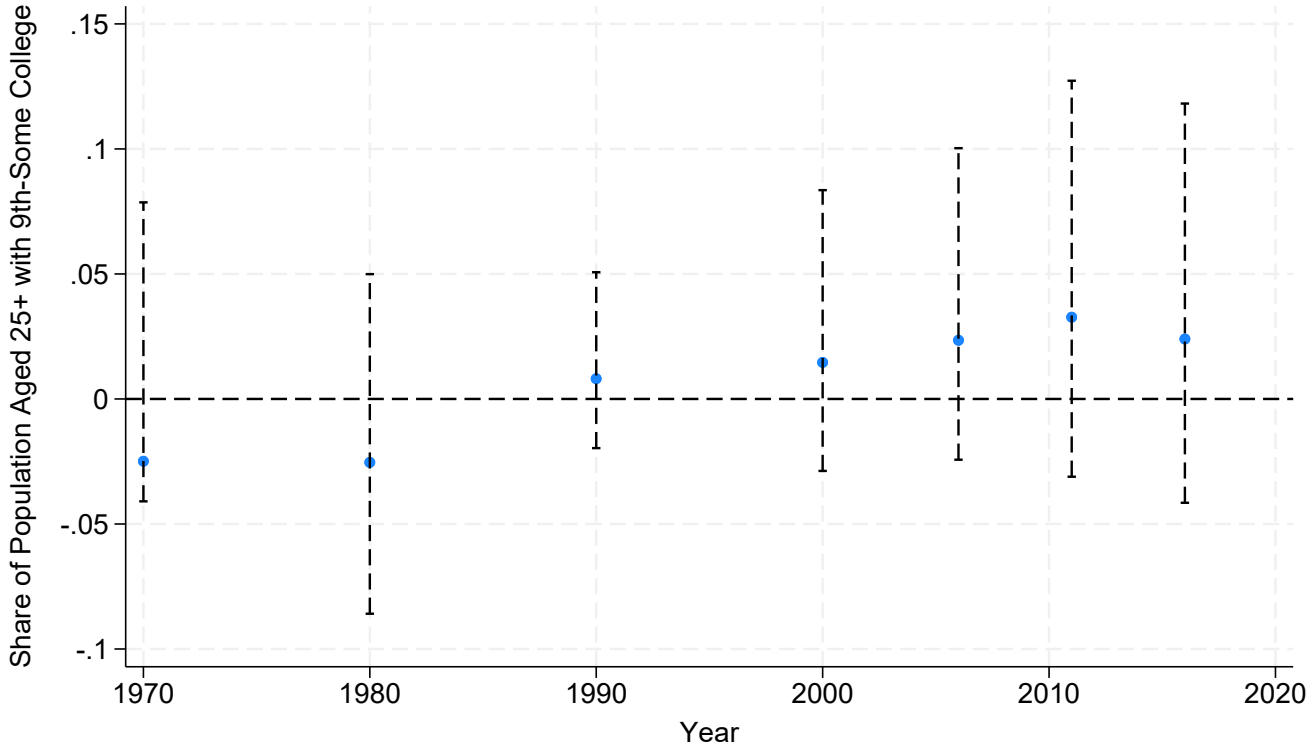
	(1) Total Market Value Per Acre	(2) Land Value Per Acre	(3) Improvement Value Per Acre
Treatment	-168856	-147545	-21311
	(19971.6)	(16001.8)	(6736.0)
	[0.11]	[0.11]	[0.25]
Control Mean	569085	457617	111468
Fixed Effects	State Border Pairs	State Border Pairs	State Border Pairs
Observations	143,637	143,637	143,637
Bandwidth	4.51 km	4.51 km	4.51 km
Kernel	Uniform Kernel	Uniform Kernel	Uniform Kernel

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors are clustered at the state level. Robust standard errors are in parentheses. Wild cluster bootstrapped pvalues and confidence intervals are in brackets. Table 14 reports spatial regression discontinuity results of residential property values across treatment state borders within the coal field boundary. The specification includes boundary segment fixed effects and uniform kernel weights. These data are 2022 market value estimations in U.S. dollars of residential properties from CoreLogic. The bandwidth used is the Calonico et al. (2014) optimal bandwidth for the total market value per acre. This bandwidth is used for all regressions in the table so that the properties included in the estimates are consistent across columns.

D Educational Attainment

Recall that Figure 8 and Figure 9 depicted spatial discontinuity estimates for the share of the population aged 25 with less than a 9th grade education. For completeness, I report here the other two educational attainment bins that are included in the Census and ACS data from 1970-2010: share of the population aged 25 and over with 9th grade to some college and share of the population aged 25 and over with bachelor's or higher. Just as in Figure 8 and Figure 9, the results for the remaining two categories of educational attainment follow similar patterns in the coal and non-coal areas, indicating that the historical legal precedent likely is not driving the patterns we are seeing in these data.

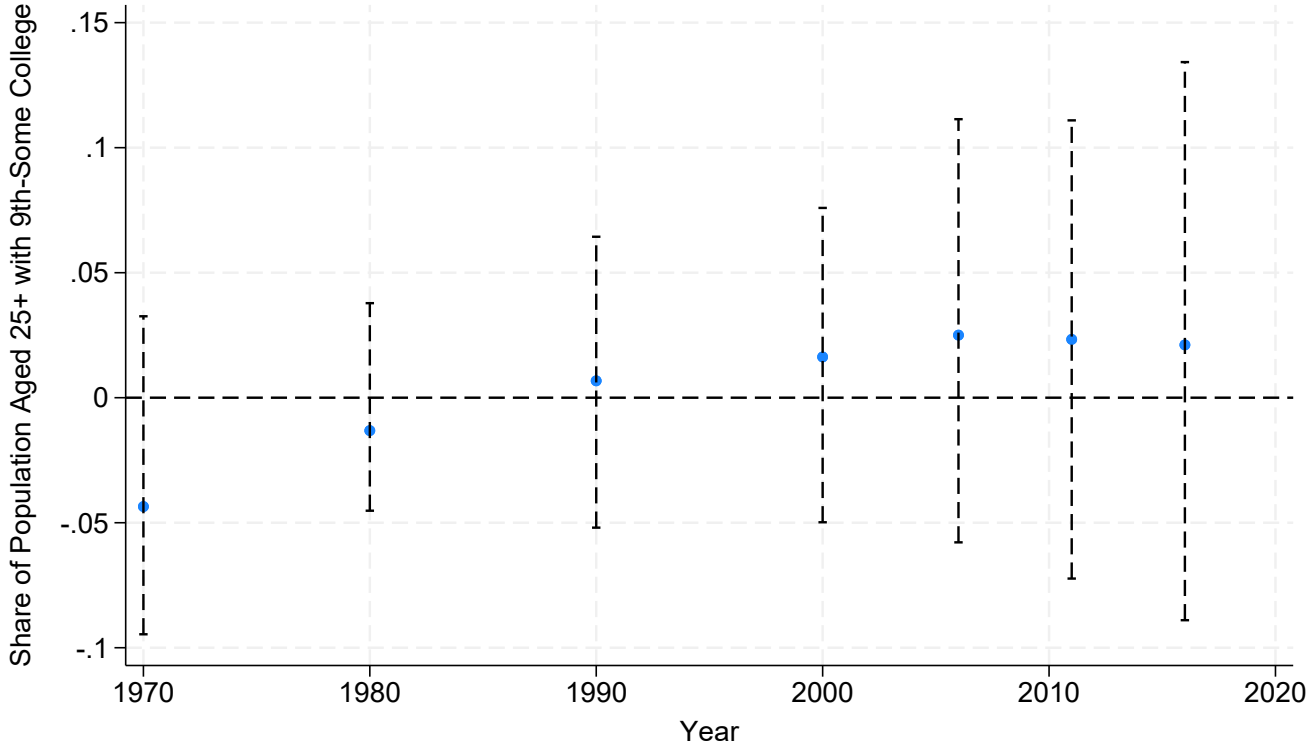
Figure 10: Spatial Regression Discontinuities of Educational Attainment (9th Grade to Some College) in Coal Areas



Notes: Figure 10 shows spatial regression discontinuities of the share of the population 25 and over that have an education level of 9th grade to some college in census tracts inside the coal field boundaries. All specifications use triangular kernels and state border fixed effects within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted.

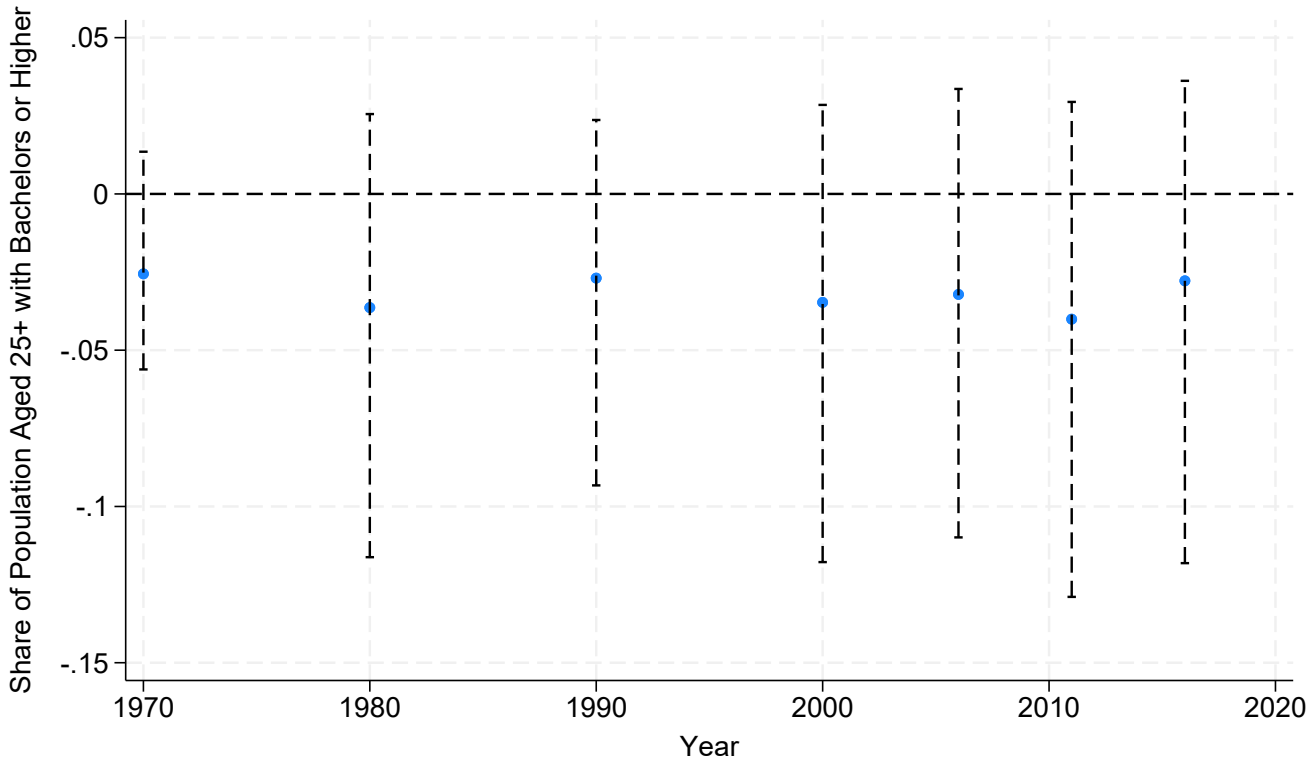
E Spatial RDs of Outcomes Over Time

Figure 11: Non-coal Areas: Spatial Regression Discontinuities of Educational Attainment (9th Grade to Some College)



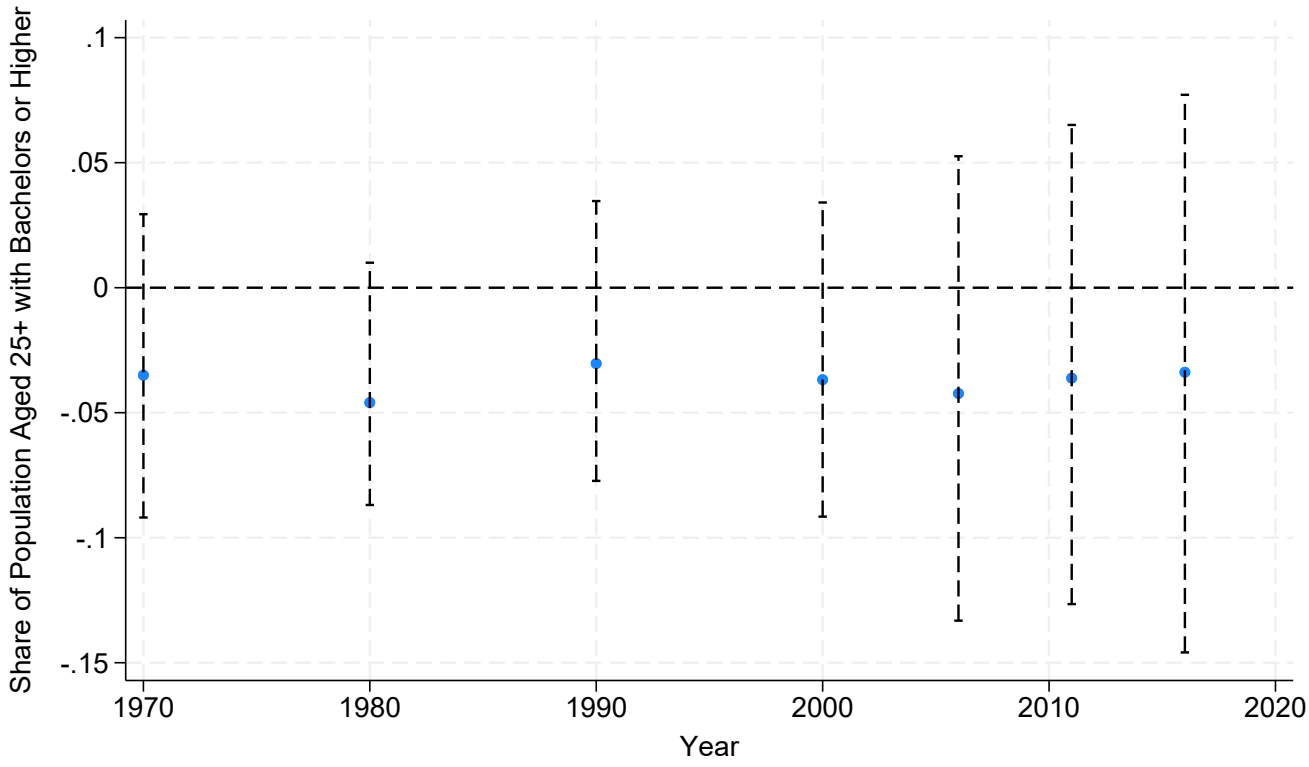
Notes: Figure 11 shows spatial regression discontinuities of the share of the population 25 and over that have an education level of 9th grade to some college in census tracts outside the coal field boundaries. All specifications use triangular kernels and state border fixed effects within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted.

Figure 12: Coal Areas: Spatial Regression Discontinuities of Educational Attainment (Bachelors or Higher)



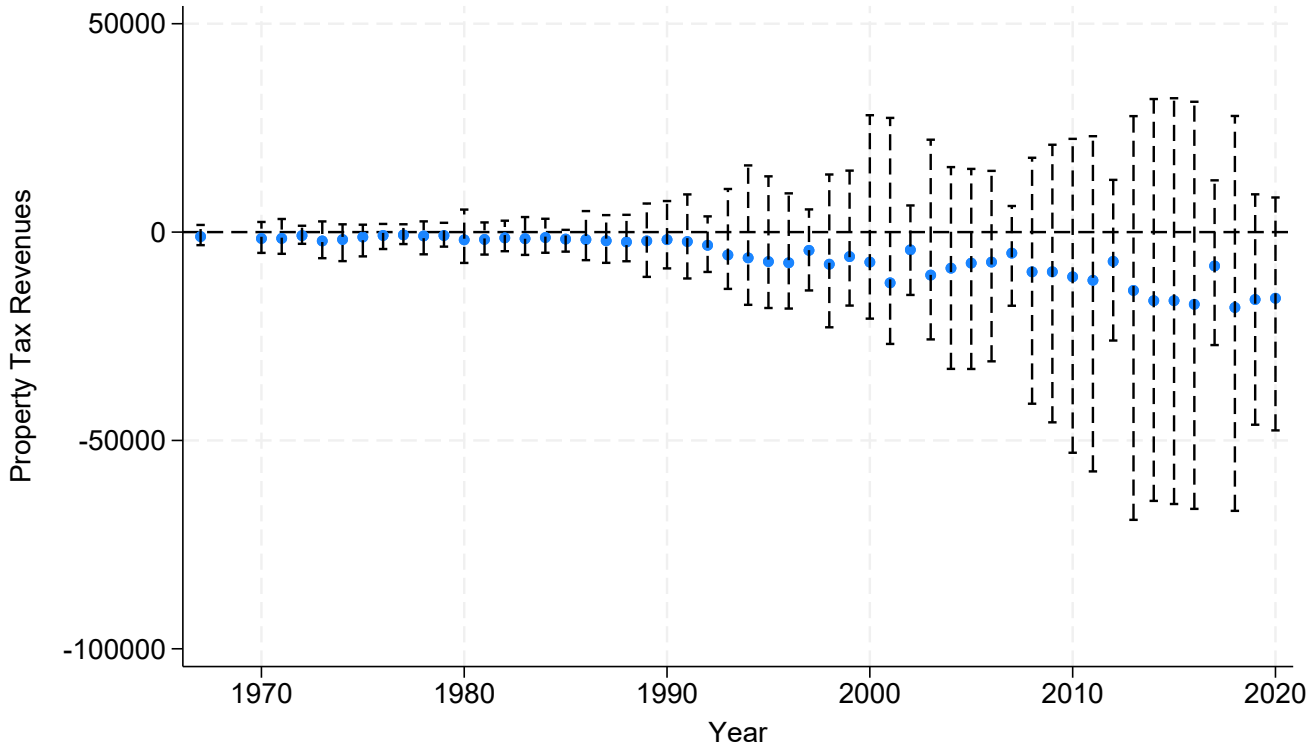
Notes: Figure 12 shows spatial regression discontinuities of the share of the population 25 and over that have an education level of bachelor's degree or higher in census tracts inside the coal field boundaries. All specifications use triangular kernels and state border fixed effects within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted.

Figure 13: Non-coal Areas: Spatial Regression Discontinuities of Educational Attainment (Bachelors or Higher)



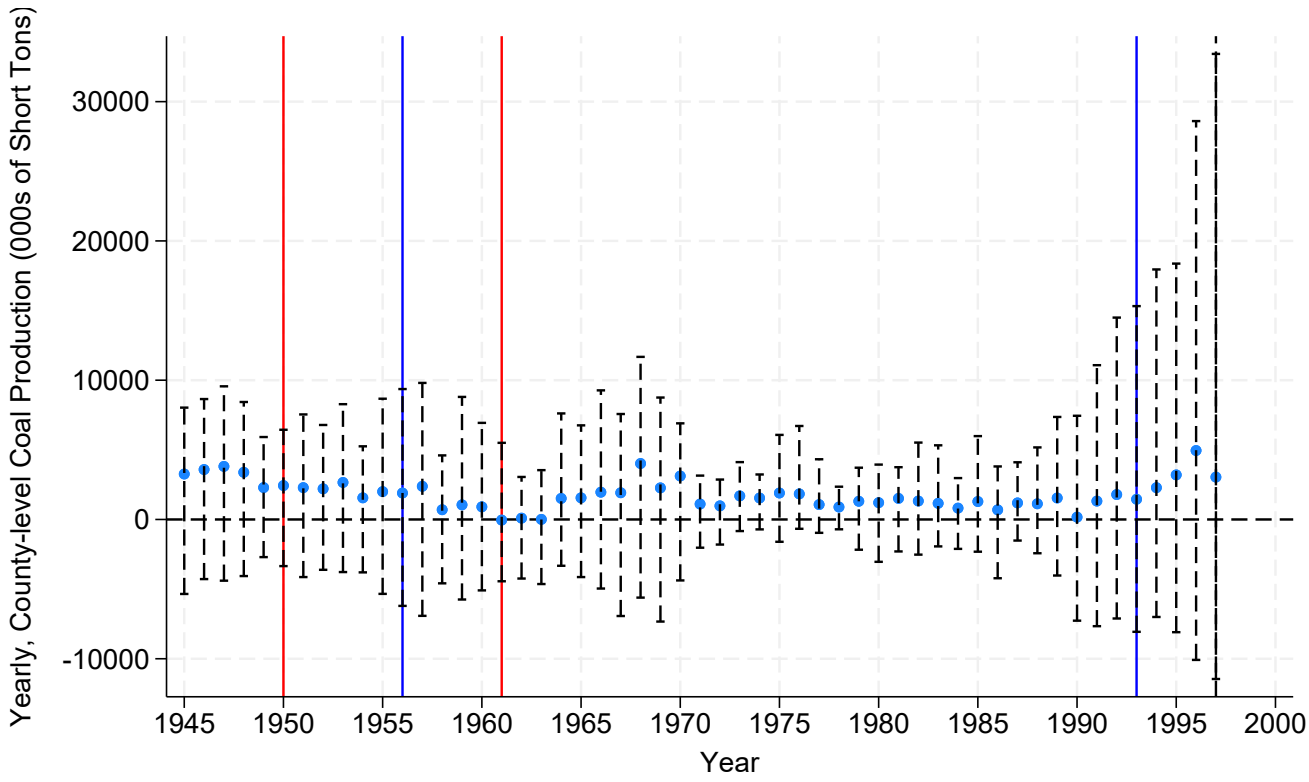
Notes: Figure 13 shows spatial regression discontinuities of the share of the population 25 and over that have an education level of bachelor's or higher in census tracts outside the coal field boundaries. All specifications use triangular kernels and state border fixed effects within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted.

Figure 14: Coal Areas: Spatial Regression Discontinuities of County-level Property Tax Revenues



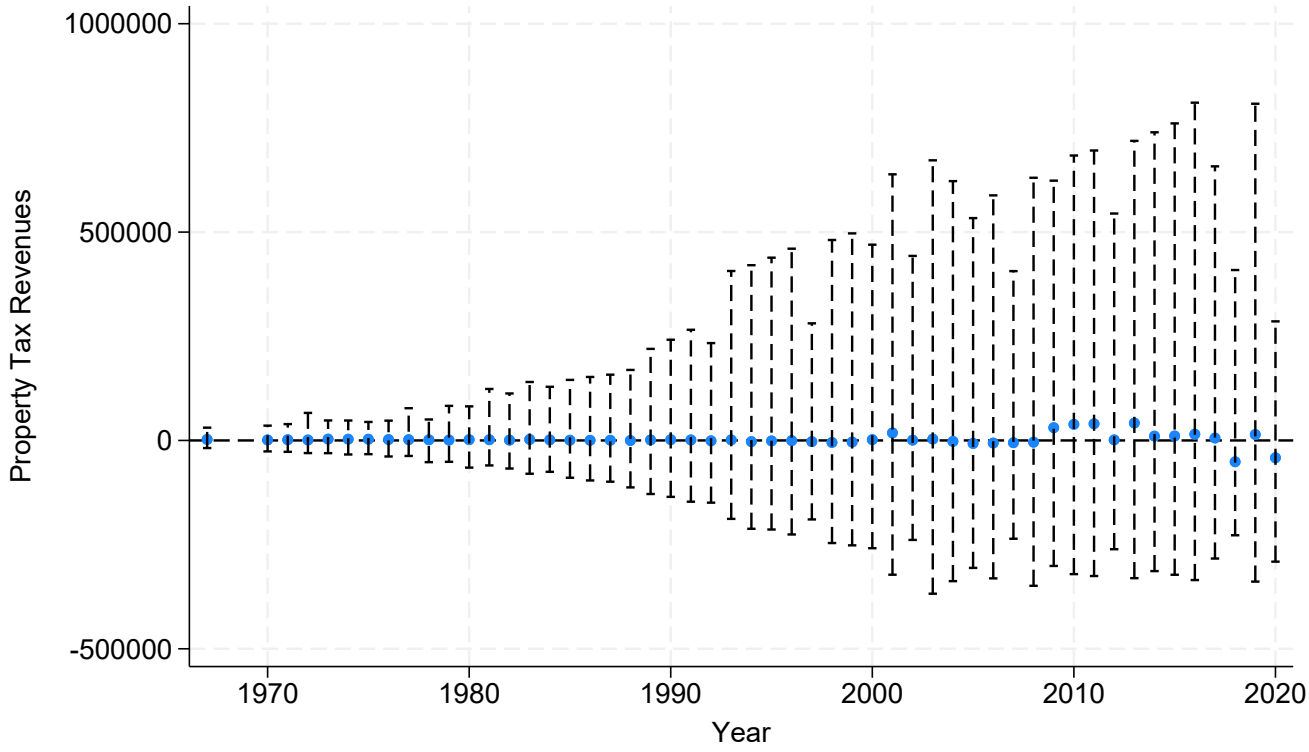
Notes: Figure 14 shows spatial regression discontinuities for each year in the Government Finances data across treatment state borders for counties inside the coal field boundaries. The outcome variable is measured as thousands of nominal dollars of property tax revenues. All specifications use triangular kernels and state border fixed effects within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted.

Figure 15: Spatial Regression Discontinuities of Yearly, County-level Total Coal Production



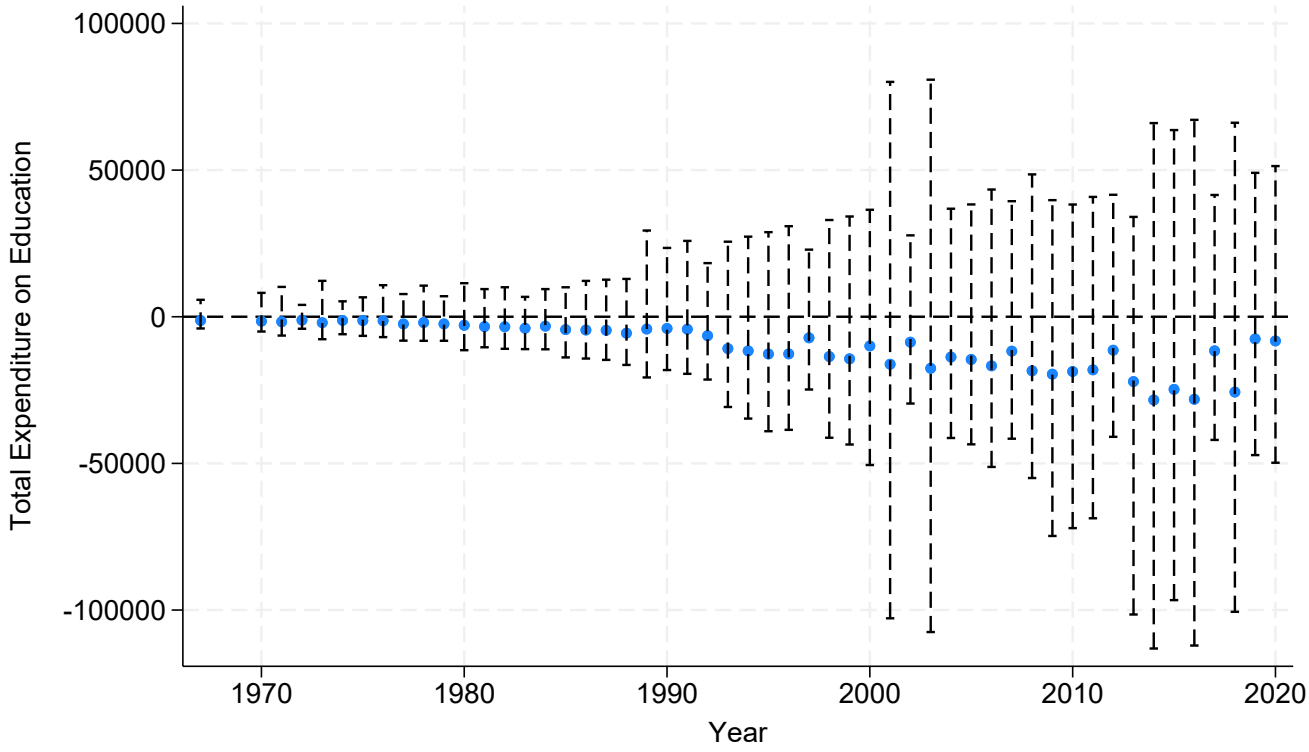
Notes: Figure 15 plots coefficients from spatial regression discontinuities of county-level coal production estimated for each year in the data. The outcome variable is measured in thousands of short tons of coal produced at the county level in a particular year. All specifications use triangular kernels and state border fixed effects and includes counties that lie within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted. The red lines mark treatment turning on and off, respectively, for Pennsylvania. The blue lines mark treatment turning on and off, respectively, for Kentucky.

Figure 16: Non-coal Areas: Spatial Regression Discontinuities of County-level Property Tax Revenues



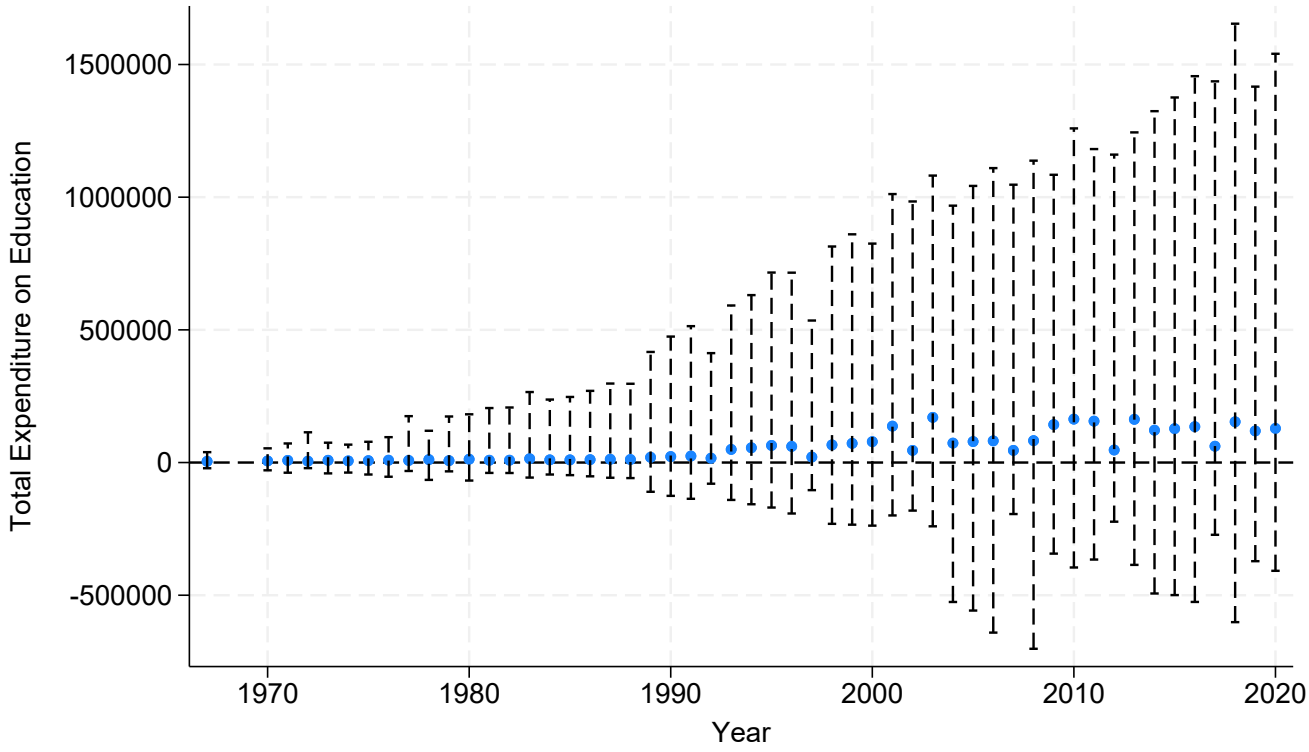
Notes: Figure 16 shows spatial regression discontinuities for each year in the Government Finances data across treatment state borders for counties outside the coal field boundaries. The outcome variable is measured as thousands of nominal dollars of property tax revenues. All specifications use triangular kernels and state border fixed effects within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted.

Figure 17: Coal Areas: Spatial Regression Discontinuities of Total Education Expenditures



Notes: Figure 17 shows spatial regression discontinuities for each year in the Government Finances of total expenditures on education for counties inside the coal field boundaries. The outcome variable is measured as thousands of nominal dollars. All specifications use triangular kernels and state border fixed effects within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted.

Figure 18: Non-coal Areas: Spatial Regression Discontinuities of Total Education Expenditures



Notes: Figure 18 shows spatial regression discontinuities for each year in the Government Finances of total expenditures on education for counties outside the coal field boundaries. The outcome variable is measured as thousands of nominal dollars. All specifications use triangular kernels and state border fixed effects within a bandwidth of 50km around treatment state borders. Wild cluster bootstrapped 95% confidence intervals are also depicted.