Industrial Policy in Declining Industries: Evidence from German Coal Mines*

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Job Market Paper - October 2024

Abstract

Industrial policy is on the rise. However, empirical evidence of how industrial policy shapes technological progress and productivity remains scarce. This paper examines a policy that aimed at boosting industry-wide productivity by subsidizing plant closures in the declining German coal mining industry. Based on newly digitized, mine-level production data, my findings indicate that the policy increased long-run productivity in three distinct ways: First, it facilitated the exit of low-productivity mines. Second, it triggered reallocation towards large, productive mines, especially in firms where the subsidy alleviated financial constraints. Third, firms invested parts of the policy-induced subsidies into machinery and infrastructure of surviving mines. The resulting within-mine productivity gains extended mines' lifespan by six years. In total, the associated reduction in marginal cost exceeded the government subsidies.

Keywords: Coal Mining, Declining Industries, Plant Closures **JEL Codes:** L52, L72, L78

*I am thankful for helpful comments by and discussions with Johannes Böhm, Carsten Eckel, Katharina Erhardt, Jan De Loecker, Andreas Lichter, Simon Martin, Nathan Miller, Helena Perrone, Philipp Schmidt-Dengler, Katja Seim, Joel Stiebale, Jens Südekum, Jo Van Biesebroeck, Frank Verboven, Kevin Williams, and Honghao Zheng. This paper also profited from participants' comments at the DICE PhD Workshop 2023 and 2024, the DICE Applied Coffee Group 2024, the IO Seminar at KU Leuven in 2023, the NoeG Annual Conference 2024, and the PhD Research Seminar at Uni Vienna 2024. Parts of this paper were written when I visited the IO Group at KU Leuven in winter 2023/2024. I am very thankful for their hospitality. I gratefully acknowledge funding from the German Research Foundation (DFG) – 235577387/GRK1974 and the Joachim-Herz-Stiftung. Lastly, I would like to thank the Montanhistorisches Dokumentationszentrum Bochum and the Statistik der Kohlenwirtschaft e.V. for their support in accessing and digitizing parts of the data. All remaining errors are my own.

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1 Introduction

Many Western economies have been facing significant changes in their industry composition, resulting from forces such as rising international trade or the advent of new technologies. Industries that were once highly relevant, such as steel production or car manufacturing, have declined for years (e.g., Bekaert et al. 2021, Dechezleprêtre et al. 2023). In a laissez-faire scenario, these industries might simply disappear, but for multiple reasons politicians strive to sustain such industries, or at least steer and decelerate their decline. For example, industrial decline and layoffs are typically regionally concentrated and induces (socio-)economic disparities in space (e.g., Berbee et al. 2024, Gagliardi et al. 2023) as well as political polarization (e.g., Autor et al. 2019, Dippel et al. 2022). Further, keeping an industry alive can serve strategic economic goals and ensure geopolitical independence or can help to overcome transitory causes for the decline.

For these reasons, politicians have an interest in supporting certain industries and pursuing industrial policies. Hence, it is crucial to understand which policies can be implemented in this context to meet the policymaker's goals in the most efficient way. However, while a large share of industrial policies is devoted to promoting declining industries, empirical evidence on the effects of such interventions remains scarce. This is due to the just recent resurgence of industrial policy (Barwick et al. 2024*b*, Juhász et al. 2022, 2023) and the focus of research on industrial policy in growing or new infant industries (Barwick et al. 2024*a*, Harris et al. 2015, Juhász 2018, Lane 2022, Manelici & Pantea 2021, Rodrik 2004) or placed-based policies after industries have declined (Cingano et al. 2022, Criscuolo et al. 2019).

In this paper, I shed light on the question of how industrial policy can enhance industry-wide productivity in declining industries, thereby actively steering the industry's decline. I study a historical episode of a specific industrial policy in the shrinking German coal mining industry in the 1960s and 1970s. At the time of the policy's introduction, the industry accounted for 4.5% of the national GDP (Federal Statistical Office of Germany 1965), faced severe import competition with oil, and was set to decline considerably. However, rather than commonly subsidizing the industry's production to decelerate the decline, the government pursued the unconventional strategy of offering closure payments.[1] Through this program, firms closed 25% of the industry's capacity. I show that this policy led to considerable productivity gains, by triggering the exit of unproductive mines, within-mine productivity growth, and within-firm reallocation towards more productive mines. This episode may have ramifications for the design of current policies in industries that are declining or hold excess capacities. My findings emphasize that the long-term survival of the industry might be achieved by consolidating industry capacities in more productive plants through targeted policies, rather than maintaining all production capacities in all firms via subsidies.

I study the policy's impact using detailed production data in physical units at the establishment level for the universe of German coal mines, which I newly self-digitized from various archive sources. Employing both reduced-form methods and the structural production approach in the spirit of Ackerberg et al. (2015), De Loecker & Warzynski (2012), and De Loecker & Scott (2022), I demonstrate that the consolidation policy led to a significant productivity increase. Relative to Belgian mines that quarried from the same cross-border coal field and had similar development trajectories before the policy, German mines saw an approximately 10% increase in labour productivity over a ten-year time span after the policy on average.

This productivity rise can be attributed to three almost equally important channels. First, the closure subsidy led to positive selection, i.e., the exit of inefficient mines. I observe a negative effect of a mine's labour productivity and total factor productivity (TFP) on its likelihood of exiting under the policy. Since exit depends on many unobserved factors that possibly correlate with productivity, I use an instrumental variable approach that leverages differences in mines' geology as an exogenous shifter of productivity for the identification of a causal effect. My preferred specification suggests that exit increased labour productivity (TFP) by 3.1% (1.5%).

Second, I show that firms used the closure subsidies to improve the productivity of their remaining mines. I compare the remaining mines of policy uptakers to non-uptakers, that both developed on similar pre-policy outcome trends, in a difference-in-differences design. I find that the subsidies alleviated the financial constraints of treated firms. The policy reduced uptaking coal firms' debt ratios by up to 15 p.p., while simultaneously boosting their stock market values by on average 30%

[1] Closure payments have only been used to reduce overcapacities in few other industries, e.g., the EU crop industry (Commission of European Union 1988), EU fishing industry (Council of European Union 2006), French steel industry (Raggi et al. 2015), or EU milk industry (Commission of European Union 2016).

and increasing dividend payouts by on average 20%. As a result, the subsidies induced more investments, which resulted in better infrastructure and technology adoption. Formerly more financially constrained firms responded more strongly to the policy. Overall, these adjustments contributed another 3.3% (4.1%) to industry-wide labour productivity (TFP) gains on average. I further show that estimated marginal costs of mines owned by treated firms fell by around 1.5%, resulting in cost savings that exceeded the government expenditures through the policy. The investments also extended the lifespan of treated mines by six years on average. Workers in treated mines profited through wage increases relative to those in mines of non-uptakers.

Third, by studying heterogeneity in mine characteristics, I show that the policy facilitated within-firm reallocation towards larger, more productive mines in multi-mine firms. This reallocation led to the emergence of a few very large and highly productive mines. Using distribution regressions in the spirit of Chernozhukov et al. (2013), I elicit the full counterfactual mine size distribution absent the policy. I find that absent the policy the largest mine would have been smaller than one-fourth of the treated mines post-policy. The observed concentration of productivity growth in a few large mines aligns with recent evidence which emphasizes that industry-wide productivity gains are often driven by a few rapidly growing 'superstar' firms (Autor et al. 2020, De Loecker et al. 2020, De Loecker & Eeckhout 2018, Stiebale et al. 2024). This reallocation channel contributed another 3.2% (1.7%) to the industry's labour productivity (TFP) gains.

Whereas the policy increased average industry-wide productivity, it also had significant distributional effects between firms. Recall that the policy's goal was to reduce capacity. In contrast to single-mine firms, multi-mine firms got around this policy target. They earned a premium for mine closures but shifted the full production volume of the closed mines to the remaining mines post-policy. I show that this caused an increasing productivity dispersion in the industry with deteriorating mines at the left tail and improving mines at the right tail of the productivity distribution. Further, I find that policy-uptaking firms revealed higher stock values, dividends, and lower debt ratios after the policy relative to non-uptakers.

The policy also caused a reallocation of output towards mines with cokeries. Cokeries refine coal to coke, a critical input for steel production. Steel production had been a reliable source of demand for coal, consuming around 40% of produced coal (Gatzka 1996). As coke cannot be substituted with oil, the steel industry did not reduce its demand for coal and coke. Hence, the policy led to a shift in mines' business model along the value chain towards more stable customer markets. Thus, reallocation led mines to adapt to and insure themselves against the upcoming decline in household demand for coal. As a side effect of this reallocation, I show that the policy increased employment in vertically integrated cokeries owned by coal firms.

While the policy laid off or retired 29,000 workers in the short-run (accounting for employment spillovers), it ultimately induced a higher survival rate of mines. A careful back-of-the-envelope calculation suggests that the extended longevity of these mines saved about 20,000 jobs per year over the post-policy horizon. I neither find positive nor negative employment spillovers to other industries in counties where mine closures took place, i.e., mine closures do not cause a deindustrialization outside of the narrowly defined coal industry.

I also thoroughly illustrate that the policy was cheaper than common alternative interventions. First, I show that price subsidies of the same volume as the implemented closure subsidies would have only sustained demand for excess coal production for two years. Moreover, wage subsidies or increased government consumption of excess coal would have quickly been more expensive policies than closure subsidies. I also demonstrate that promoting within-firm mine mergers would not have achieved similar productivity and efficiency gains as the closure subsidy.

My results are informative to policymakers about how to conduct industrial policy in declining industries, in industries with (temporary) costly overcapacities (e.g., milk production), or in which the decline of aggregate output is a policy goal (e.g., phase-out of non-renewables).

Related Literature. This paper relates to several strands of the literature that motivate research on industrial policy in declining industries.

First, a large literature has documented the misallocation of production across countries (Hsieh & Klenow 2009, 2014, 2018, Hsieh et al. 2019, Restuccia & Rogerson 2017), industries (Adamopoulos et al. 2022, Hsieh & Klenow 2009, 2014, 2018) and firms (Asker et al. 2019, 2020) as an important source of productivity losses. These papers examine the drivers or obstacles of reallocation such as trade liberalization and import/export competition (Pavcnik 2002), innovation (Hsieh & Klenow

2009, 2018) or demand fluctuations (Collard-Wexler 2013, Allcott et al. 2016). In my paper, I take these insights to declining industries and show that reallocation increases industry-wide productivity. A novel aspect of my findings is that this reallocation occurs within firms across their establishments. My results also support the notion that financial constraints are a key hurdle to reductions in misallocation (Midrigan & Xu 2014).

Second, I address an extensive literature discussing the pros and cons of industrial policy (Juhász et al. 2022, Juhász & Steinwender 2023, Rodrik 2004, 2009). Common concerns about industrial policy include its high cost, lack of precise targeting, and potential to discourage innovation. In my paper, I show that industrial policy can be less costly than expected. I further show that firms adopt their business model along the value chain and adopt new technologies. By looking at exit subsidies in a declining industry, I also provide a new perspective on conducting industrial policy. Up to now, most evidence on the effects of industrial policy has been provided for rising infant industries (Juhász 2018, Lane 2022), trade policy (Brandt et al. 2017, De Loecker 2011, Orr & Tabari 2024, Pavcnik 2002, Topalova & Khandelwal 2011) and standard policies such as price, wage, investment or place-based subsidies (Becker et al. 2010, Criscuolo et al. 2019, Ehrlich & Seidel 2018, Garin & Rothbaum 2024, Heblich et al. 2022, Kline & Moretti 2014, LaPoint & Sakabe 2021, Siegloch et al. 2024).[2] I demonstrate that closure subsidies can preserve more jobs in the long term compared to price or wage subsidies, assuming a fixed policy budget.

Third, my findings add to a growing literature that investigates the determinants of firm- and establishment-level productivity and productivity dispersion. Various factors have been identified, such as competition intensity (Backus 2020, Stiebale & Szücs 2022, Syverson 2004), ownership (Braguinsky et al. 2015), import competition (Amiti et al. 2019, De Loecker & Warzynski 2012, Lileeva & Trefler 2010, Topalova & Khandelwal 2011), exporting (De Loecker 2013), manager ability (Rubens 2023*a*) or FDI (Arnold & Javorcik 2009, Lu & Yu 2015). My paper sheds light on the role of policy interventions and financial constraints in declining industries. I find that the policy increased overall productivity as well as productivity dispersion. This allows me to quantify the role of government policies in encouraging productivity growth, which up to now has been less

[2] An exception is Heim et al. (2017) who look at EU state aid for firms in business crises. They find that such rescue policies improved the survival rate of treated firms.

extensively studied (Syverson 2011), by using the context of German coal mining.

Fourth, I engage with the literature on the impact of consolidation on productivity (Grieco et al. 2018, Rubens 2023*b*), profitability (Braguinsky et al. 2015), and input and output market power (Guanziroli 2022, Miller & Weinberg 2017, Rubens 2023*b*, Prager & Schmitt 2021, Schmitt 2017). By highlighting within-firm reallocation across plants, I provide evidence for a new mechanism through which consolidation policies affect plant- and firm-level productivity as well as markups and wages. In line with Aghion et al. (2015) who show that industrial policy can lead to strong productivity growth, especially in competitive industries, I show that industrial policy in coal mining creates substantial productivity gains in the light of import competition from oil.

The remainder of the paper is structured as follows: I first explain the institutional setting in Section 2. I then describe the data, the TFP and markup estimation, and the empirical analysis in Sections 3 and 4. In Sections 5 and 6, I present the results of the paper and discuss potential mechanisms before I provide robustness checks and conclude by discussing the implications of my results in Sections 7 and 8.

2 Institutional Setting

In this section, I give an overview of the German coal mining industry and its decline.

Historical Background. Coal mining has been a crucial component of the West German economy since the 19th century. Figure 1 illustrates the location of all post-WW II mines across the three coal districts *Aachen* (South West), *Ruhr* (center), and *Ibbenbüren/Lower Saxony* (North). During WW II, coal mines were essential energy providers for German steel and arms factories, with output peaking in 1939 at the onset of the war. After the war, the industry quickly recovered from destroyed mines, fueled by the energy demand for the country's reconstruction.

In 1952, Germany joined the European Coal and Steel Community (ECSC), which abandoned tariffs and import restrictions between its member states Germany, France, Italy, Luxembourg, the Netherlands, and Belgium. However, even after joining the ECSC, intra-European coal trade remained relatively insignificant for Germany. During the 1950s and 1960s, coal imports (exports)

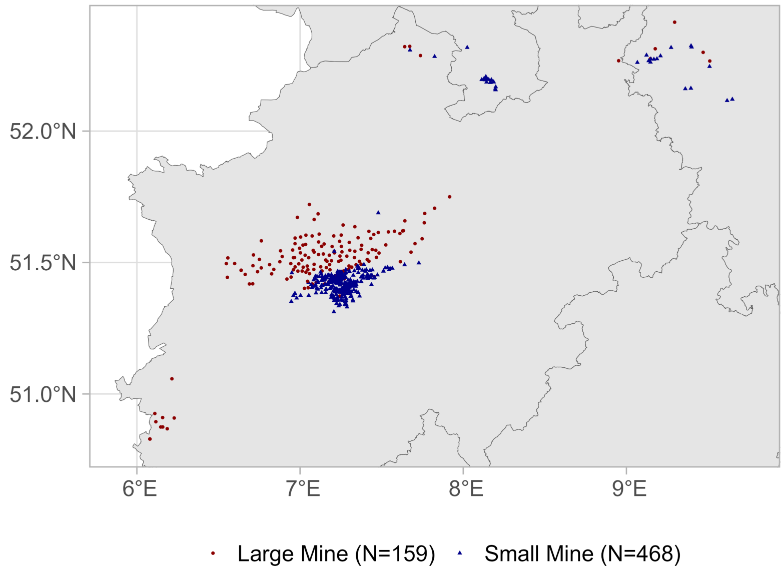


Figure 1: Geographical Distribution of Mines

Note: This plot shows the location of all mines which operated after 1947. Large mines are all mines that reported detailed production data. Small mines are all others. Merged mines are shown in their original pre-merger separation. Federal state borders of Northrhine-Westphalia included.

accounted for 10 (15) million tonnes annually, representing only 8% (11%) of the output of German mines (see left panel of Figure A1 in the Appendix). Imports to Germany did not increase because German mines were more productive than their main competitors, i.e., Belgian and French coal mines (see right panel of Figure A1).[3] Exports did not rise because mines produced at full capacity in the 1950s and due to the breakthrough of oil all over Europe from 1960 onwards.

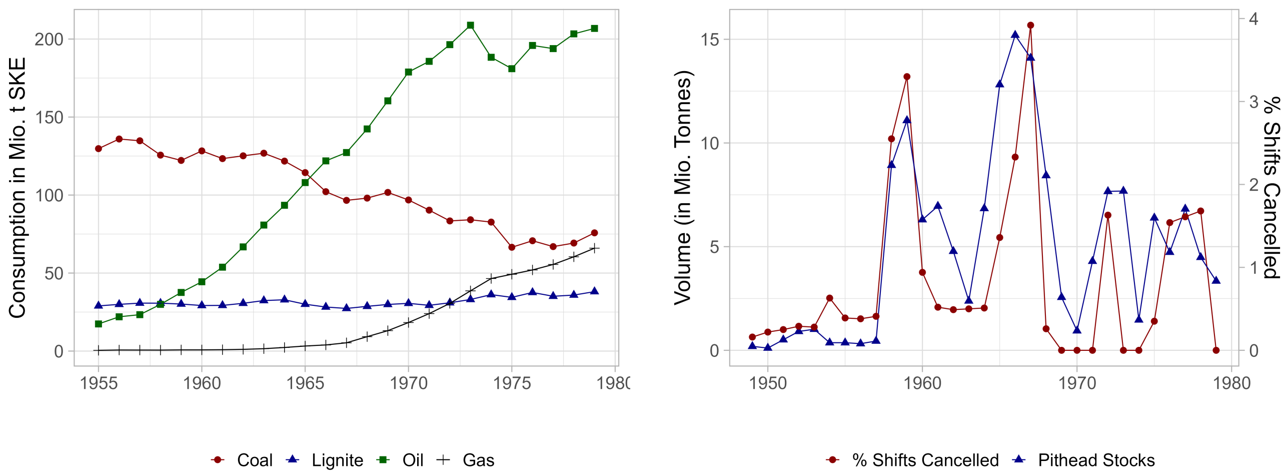
Instead, coal imports from the US put pressure on the industry in the late 1950s as freight fees decreased by 80% (Bundestag 1959*b*). In response, Germany introduced tariffs of 20 Deutsche Mark [DM]/tonne on non-ECSC coal beyond a tariff-free contingent of 5 million tonnes annually, effectively capping coal imports at this threshold (Bundestag 1959*a*).[4]

By the late 1950s, coal mining accounted for 8% (3%) of the German industry (total) employment, 60% of energy production, and 6% of GDP (Federal Statistical Office of Germany 1960).

Decline. In the 1950s, Germany began importing oil as a substitute for coal (Fritzsche & Wolf

[3] Also, coal prices were lower than in Belgium and France in the 1950s (see, e.g., High Authority (1956*c*)).

[4] Germany also introduced a one-year advertisement ban for oil in 1959 (Gatzka 1996) and several other small but relatively ineffective measures (Stilz 1969).



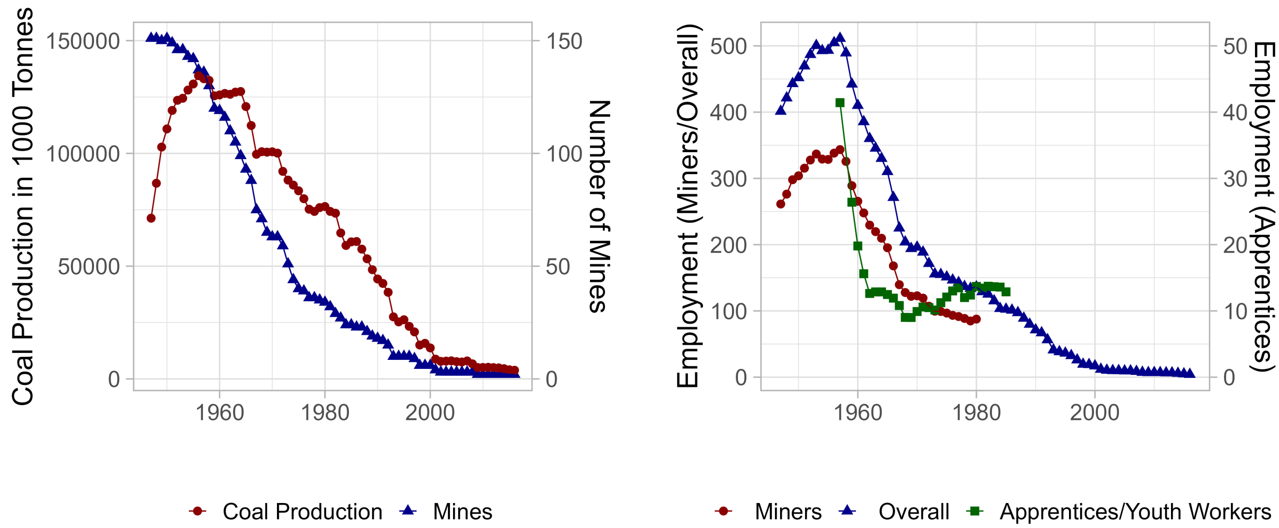
(a) German Energy Split

(b) Measures of Overcapacities

Figure 2: Energy Split Transformation and Changes in Coal Demand

2023) due to lower oil prices and improved access (i.e., lower shipping costs, diplomatic relations with the Near East).[5] Even, the removal of a VAT exemption for heavy oil (Bundestag 1960) did not slow down this trend. The left panel of Figure 2 shows the rise of oil in the German energy mix. The right panel illustrates the resulting overcapacities in coal mines. After 1957, excess coal had to be stored in pithead stocks (i.e., coal storages) and 3% of work shifts were cancelled. There was insufficient exit to eliminate overcapacities. Mines did not reduce their production, instead coal firms expected that more coal would be needed soon when the German economy experiences a new upswing (Bundestag 1959*b*). Coal firms underestimated the impact of oil, predicting only a 2-3% decline in coal demand due to oil imports (Gatzka 1996, Unternehmensverband Ruhrbergbau 1961), while anticipating a 10-15% increase in coal production by 1965 (Der Spiegel 1958*b*). The High Authority of the ECSC, which oversaw conduct in the coal industry, even expected an increase in German coal production by 30% until 1975 in 1957 (Burckhardt 1968). The first coal mines shut down in the early 1950s. Figure 3 shows the decline of the industry in terms of production and employment. From the early 1950s to 1970, the number of mines collapsed by 50%, output by 25%, total and miner employment by 60% and the number of apprentices by 75%. Figure A2 in the Appendix also shows the geographical distribution of the decline with

[5]To illustrate this substitution, in Table A1 of the Appendix, I show that the demand elasticities of coal with respect to the coal and oil price both increased in absolute terms after the uprise of oil. I instrument the coal price with average coal worker wages and the oil price with import wholesale prices from Saudi-Arabia.



(a) Production (Units)

(b) Employment in 1000s

Figure 3: Scope of the Industry Over Time

earlier closures of small mines in the South of the *Ruhr* coal district.

The economic effects of mine closure were non-negligible given that 35% of all industry workers in counties with mine closures were employed in the coal industry in 1962 (Statistisches Landesamt Nordrhein-Westfalen 1964). For example, on average a mine closure led to a persistent fall in the municipality (worker) population by 5-10% (Figure A3 in the Appendix).

Rationalisierungsverband des deutschen Steinkohlenbergbaus[6] (henceforth *RV*). This paper examines the consequences of the *RV*, a policy that became effective in 1963. The policy aimed at incentivizing the closures of inefficient mines and boosting the productivity of remaining mines (Bundestag 1963). The main policy instrument was a closing premium of 25 DM per tonne of mine-level average production per annum between 1959 and 1961. The premium represented almost half of the market price. Half of the premium was paid by the government and half by the other firms in the coal industry. This premium structure was meant to capture the positive spillovers of closures on other firms. Only mines that would not run out of coal deposits shortly were allowed to take up the policy. However, all large mines met this criterion.

Given the urgent need for a capacity reduction around 1960, the policy was passed quickly, came unanticipated, and asked for soon closure decisions. In Figure A4 in the Appendix, I show that

[6] In English: Economization Union of the German Coal Mining Industry.

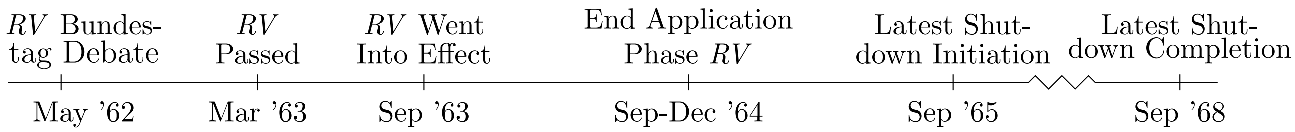


Figure 4: Timeline of the *RV*

those mines closed through the *RV* did not show anticipatory changes in output, employment, or productivity relative to non-exiting mines before the policy.

Figure 4 describes the policy rollout. After the law became effective in 1963, mine closures had to be announced within only one year and initiated within two years. By 1968, all mine closures had to be completed. The premium was only paid for coal fields that were permanently closed.

Mines that closed during the phase of the parliamentary debate but before the law became effective (May 1962 - September 1963) were also eligible, but only received 12.5 DM per tonne, the publicly financed premium. This upfront part of the policy was called *Vorausaktion*[7].

The policy closed mines with a pre-closure capacity of 31.5 million tonnes per annum, or around 25% of the overall industry output. Besides a few partial closures (i.e., only some coal fields of a mine were closed), the policy encompassed the closure of 23 large and 14 small mines. The *Vorausaktion* accounted for 8 out of the 31.5 million tonnes. Figure 5 plots the mine closure dates. Between 1962 and 1968, all closures were related to the *RV*. Few mines with only partial closures due to the *RV* closed after the 1960s. Overall, the policy scheme included payments of 590 million DM (in real terms of 2020: 1.5 billion Euro) - government and competitor payments combined.

The policy had two effects on workers illustrated in Figure A5 of the Appendix. First, the left panel shows that many workers were laid off, leading to a spike in the share of terminated contracts during the mid-1960s closure phase.[8] Using county-level employment data, I also show that there is a persistent decrease in the county-level number of coal workers in counties with closures due to this policy (right panel). There are no short-run spillovers to other industries. Second, workers who remained in the industry were partly shifted between mines. This resulted in a peak in the share of incoming workers who had previously worked at another mine.

Figure 6 compares how labour productivity[9] in the German and Belgian coal mining industries

[7] In English: Upfront payment.

[8] A high share of workers were sent to early retirement (German Federal Commissioner for Coal 1968).

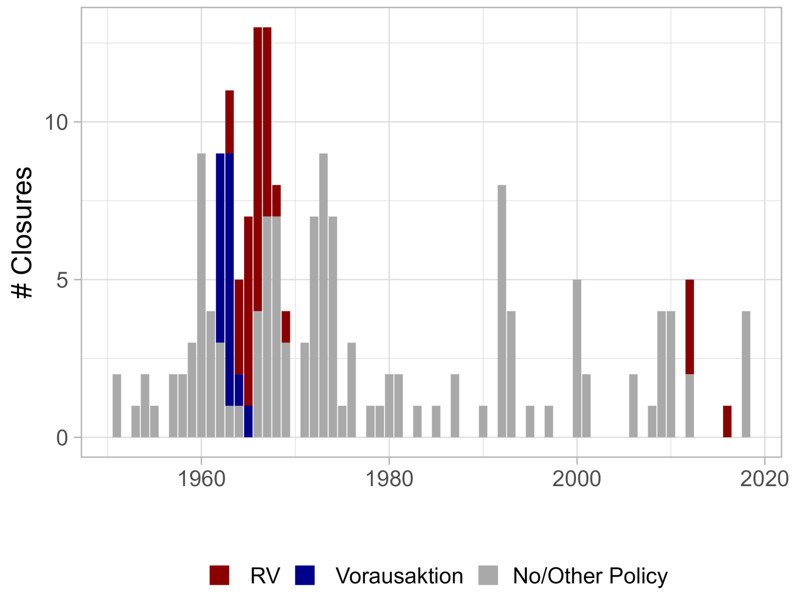


Figure 5: Closures by Supporting Policy

evolved around the *RV*. Belgium developed similarly to Germany before the policy and quarried from the identical cross-national coal field. Labour productivity increased more strongly after the *RV* in 1963 in Germany than in Belgium (on average 10% difference, in 1971: 12% difference).

Price Setting and Conduct. All German coal firms sold their coal exclusively through three (after 1958: two) retail organizations, which they jointly owned.[10] These retail organizations were run as coal syndicates through which firms negotiated binding prices. Price deviations would have been heavily sanctioned due to the explicit contracts (Geitling 1956). As the retail organizations should not make profits as determined in the contract, there was no double marginalization. The coal firms reported their expected output for the next quarter and year as well as broad expectations about the upcoming years (Geitling 1960).

Even though each coal firm only belonged to one retail organization, actual competition between the retail organizations was doubted (Carret 2023, Gatzka 1996). They had their offices in the same building (High Authority 1956*b*, Der Spiegel 1963) and often announced (almost identical) price lists simultaneously (Gatzka 1996, High Authority 1965). Also, the ECSC allowed them to

[9] Later on, I will use total factor productivity as the baseline measure of productivity. However, data availability only allows me to estimate total factor productivity for German mines, so that I compare Germany and Belgian in terms of labour productivity.

[10] Similar coal syndicates also existed in the Netherlands, Belgium, and France at the time (Der Spiegel 1958*a*).

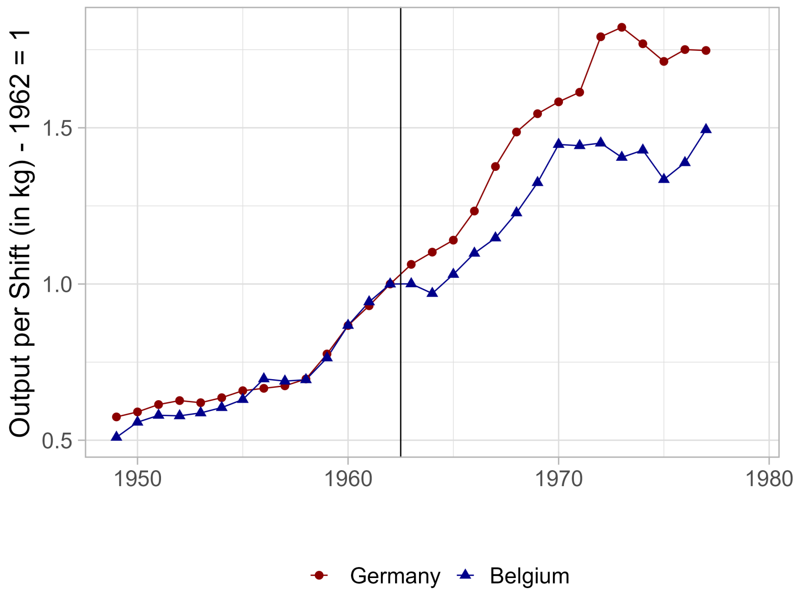


Figure 6: Comparison of Labour Productivity Development in Germany and Belgium

collaborate to ensure the availability of the different coal types, to avoid harm to employees by smoothing demand across mines and to jointly save transportation costs (High Authority 1956*a*,*b*). Effectively, price setting in the retail organizations at the industry level left firms with only choosing their production output level as the main strategic variable.

3 Data

In this section, I present my data at hand and how I estimate total factor productivity, an essential variable to my analysis later on.

3.1 Mine-Level Production Information

I build a novel dataset on the universe of German mines from the 1950s to 1970s. For this, I digitized various data sources - primarily from the *Yearbooks of the German Coal Mining Industry*, the *Establishment Statistics* by the *Statistics of the Coal Industry e.V.*, and the *Annual Reports of the RV*. Other sources for mine-level geological information will be named below.

Sample Construction. For my analysis, I abstract from 'small' mines as well as mines from the

Saar area. 'Small' mines are characterized by a very low output[11] and usually are run by industry companies or municipalities to exclusively serve their own consumption. Saar mines are excluded due to the region's unique post-war status as a French protectorate until 1957. Even after rejoining Germany, a significant portion of Saar's coal production was allocated to reparation payments to France, thus only partially contributing to the German coal market. The final, remaining sample encompasses about 90% of the German annual output, covering approximately 150 mines in 1952, with around 35 mines still active in 1980. I restrict my sample to data until 1971 as other policy interventions took place in the early 1970s, e.g. all coal firms were forced to merge into one entity.

Production Data. The dataset contains detailed mine-level annual input and output data. For output, the data includes both raw physical output (including non-coal content) and pure coal output in tonnes. For inputs, I observe four different inputs in physical units. First, for labour I observe aggregate employment, employment of below- and above-surface workers and administration workers as well as annual per-shift average wages. I can also track inflows of workers from other mines and from non-mining industries. Lastly, the number of cancelled shifts for various reasons such as accidents, production breakdowns, and a lack of demand is available.

Second, I observe capital, i.e., machinery power in kWh. Third, there is data on the electricity consumption in kWh. Fourth, the data includes pit wood consumption in cubic meters. Pit wood is used to construct and stabilize tunnels and as an energy source. I collect annual data on pit wood prices by cubic meters from Schroeder (1953) and the *Statistical Yearbooks of Germany.*

Geological Mine-Level Data. Mine-level productivity is heavily determined by geological factors. For each mine and year, I know the maximum depth, the coal field size (i.e., the mining rights), and the number of seams (coal layers). Further, I observe the type of coal deposits a mine stores and quarries in its field as well as the average thickness and angle of the coal layers. Lastly, I gather data from the *Geological Office of Northrhine-Westphalia* on the thickness of the marl soil layer which is a sediment layer located between the surface and the coal layer. It mainly determines the depth of the coal deposits and set-up costs of the mine.

[11]The median output of a small (large) mine is 6.3 (1,135.3) tonnes per annum.

Technology Adoption. Data on the annual number of mining positions used for manual and mechanical mining as well as the share of production using these technologies is available.

Price Data. I know mines' prices through price lists of the retail organizations published in the *Statistical Yearbook of Germany* and the *Statistical Yearbooks of the German Coal Mining Industry*. I match prices to mines based on the 1963 allocation of firms to retail organizations. Prices changed multiple times a year, so that I calculate a time-weighted annual average price.
Mines sold various types of coal (e.g., fat coal, anthracite, gas coal) in different forms (e.g., cleaned/uncleaned, nugget/fine). However, due to limited differentiation in production, I treat mines as single-product establishments, following existing literature (Delabastita & Rubens 2023, Rubens 2023*a*,*c*). I employ coal prices for the common 'Nut III' form. The mine-year coal price then is a mine-level weighted average price of the mine-level production across coal types.

Firm-Level Financials. I collect firm-level stock values, dividends as well as assets and debts of stock market-listed firms from the annual *Salinger's Aktienführer*.

Descriptive Statistics. Table A2 in the Appendix summarizes all data discussed above.

3.2 Productivity Estimation

A main variable in my analysis is productivity. I will use two measures of productivity. First, labour productivity, i.e., output per worker shift, is a simple proxy for productivity, suits the labour-intensive production process in the industry well, and can be calculated directly from the data. Second, I estimate total factor productivity (TFP) to account for the consumption of all inputs beyond labour.

Production Function Estimation. I combine insights on structural production function and markup estimation by Ackerberg et al. (2015), De Loecker & Scott (2022), and De Loecker & Warzynski (2012). I start with the production function of a mine i in year t:

$$Q_{it} = \min\{\beta_{m,it} M_{it}, F(K_{it}, L_{it}, \beta)\Omega_{it}\} exp(\epsilon_{it}) \tag{1}$$

where Q_{it} is physical output in tonnes of coal which is produced with a production technology of capital K_{it}, labour L_{it}, and material input M_{it}. In my data, K_{it}, L_{it}, and M_{it} are given by the machine power (in kWh), worker shifts, and amount of pit wood (in cubic metres) - all in physical units. Ω_{it} is a Hicks-neutral productivity shock. The measurement error is given by ϵ_{it}.

I assume a Leontief production function where $F(K_{it}, L_{it}, \beta)$ is Cobb-Douglas with time-invariant output elasticities $\beta = \{\beta_l, \beta_k\}$ (see, e.g., Avignon & Guigue (2023), De Loecker & Scott (2022), Hahn (2024), or Rubens (2023*b*)), i.e., mines produce with a fixed ratio of pit wood and the combination of labour and capital. Pit wood, primarily used for stabilizing tunnels and as an energy source, is difficult to substitute with labour or capital. However, labour and capital can be substituted for each other.

Using physical input and output data avoids that estimation results are prone to input and output price biases (De Loecker & Scott 2022). The Leontief production function avoids identification concerns for multiple flexible inputs (Gandhi et al. 2020) and also reduces concerns about unobserved conduct. Since coal is not a differentiated product, concerns about unaddressed quality biases are minimized.

I rely on standard timing assumptions of input choice (Ackerberg et al. 2015, Levinsohn & Petrin 2003, Olley & Pakes 1996) and assume that productivity follows a first-order Markov process:

$$\omega_{it} = g(\omega_{i,t-1}, [RV\ Exposure_j], Post_{i,t-1}, [RV\ Exposure_j] \times Post_{i,t-1}, Pr(Exit)_{it}) + \zeta_{it} \tag{2}$$

where $\omega_{it} = ln(\Omega_{it})$ is a function of its lagged value, the policy, the likelihood of market exit in the next year, $Pr(Exit)_{it}$, and an exogenous productivity shock (ζ_{it}). Policy exposure is given by (i) the share of pre-policy, firm-j-level production which has been closed due to the policy ($[RV\ Exposure_j]$), (ii) lagged values of a before-after policy dummy, $Post_{it}$, which turns one after the majority of exits from after 1965 onwards, and (iii) the variables' interaction.

First, I exploit that rearranging the logged production function gives an explicit control for productivity which identifies the measurement error ϵ_{it}:

$$\omega_{it} = ln(\Omega_{it}) = ln(\beta_{m,it}) + m_{it} - ln(F(K_{it}, L_{it}, \beta)) \tag{3}$$

We run a two-step estimation procedure. I first run an OLS regression of logged output on $ln(\beta_{m,it})$ and m_{it} where I approximate the former using a high-order polynomial of logged labour, capital, and materials (l_{it}, k_{it}, m_{it}), i.e., $\phi(.)$, as well as variables affecting input choices, X_{it}, such as mine depth and age, the existence of a cokery, number of coal layers, wages, and year fixed effects:

$$q_{it} = \phi(k_{it}, l_{it}, m_{it}, X_{it}) + \epsilon_{it} \tag{4}$$

This step provides an estimate for the predicted output, denoted as $\hat{\phi}_{it}$. The moment conditions, which identify the production function coefficients $\beta = \{\beta_l, \beta_k\}$, are given by:

$$E[\zeta_{it}(\beta) \begin{bmatrix} l_{i,t-1} \\ k_{it} \end{bmatrix}] = 0 \tag{5}$$

Timing assumptions denote that capital is chosen before labour. Labour has been quite flexibly adjustable. For example, in response to the policy 87,000 jobs were cancelled or shifted between mines immediately. An estimate for ω_{it} is then calculated by:

$$\hat{\omega}_{it} = \hat{\phi}_{it} - ln(F(K_{it}, L_{it}, \hat{\beta})) \tag{6}$$

Our baseline TFP estimates yield a correlation of 0.795 with labour productivity.

For markup estimation, I rely on De Loecker & Warzynski (2012) and De Loecker & Scott (2022). Cost minimization with respect to input choices gives markups $\hat{\mu}_{it}$ and marginal costs $\hat{c}_{it}$:

$$\hat{\mu}_{it} = \frac{P_{it}}{\hat{c}_{it}} = \frac{1}{\frac{\eta^L_{it}}{\hat{\beta}_l} + \eta^M_{it}} \qquad \hat{c}_{it} = \frac{P_{it}}{\hat{\mu}_{it}} \tag{7}$$

where P_{it} is the per-tonne price for coal and η^L and η^M are the revenue shares of labour and materials expenditures, corrected for the measurement error. Table A3 in the Appendix provides the estimation results, i.e., output elasticities, scale parameters and markups, for the baseline approach and a robustness check with a Cobb-Douglas production function with electricity as substitutable material input. The production is labour-intensive and the scale parameter is not significantly different from one. To ensure that my results are not sensitive to strong assumptions on the production technology, I will provide several robustness checks in Section 6.

4 Empirical Strategy

To examine *RV*'s effect on industry-wide productivity, I study mine-level outcomes along various margins. Figure 6 showed that labour productivity in German relative to Belgian mines grew due to the policy but the underlying channels remain unclear. My empirical strategy is twofold. First, recall that the policy intended to push out unproductive mines. I study this extensive margin effect of the policy by examining whether productivity actually is a determinant of exit through the policy. Second, I study potential (un)intended side effects of the policy. I look at the mines' changes in production at the intensive margin, i.e., whether market shares are reallocated to more productive mines and whether firms use the policy to improve their productivity. I explain all steps consecutively below.

Extensive Margin. From an ex-ante perspective, it is unclear whether exit is negatively correlated with productivity, which was the main policy goal. Admittedly, unproductive mines with higher marginal costs are more likely to be closed ceteris paribus. However, firms will also consider output spillovers from closing a mine on their remaining mines, which are heterogeneous across mines. For example, multi-mine firms internalize some spillovers in their remaining mines if they shut down a mine. Single-mine firms cannot do so as they close their only mine. Also, the costs of closing a mine could be very heterogeneous and potentially higher for machinery-heavy, productive mines.

To examine the relation between mine-level closures and productivity, I run a cross-sectional regression of a closure dummy on mine-level productivity and controls:

$$1[Closure\ via\ RV]_i = \alpha\ (+\ \lambda_j) + \gamma_d + \theta Prod_i + X_i'\zeta + \epsilon_i \tag{8}$$

where $1[Closure\ via\ RV]_i$ is a dummy turning one if a mine i closed through the *RV*. The constant is given by α and $Prod_i$ is a measure of mine i's productivity right before the policy (1959-

1961), either labour productivity or TFP. I include coal-district fixed effects, γ_d, for the districts *Aachen*, *Ruhr*, and *Ibbenbüren/Lower Saxony* to account for region-specific drivers of exit. In some regressions, I add firm fixed effects, λ_j, to distinguish between across- and within-firm variation.

A simple OLS regression likely yields biased results. First, expectations about a mine closure can affect productivity shortly before the closure (*reverse causality*). Second, mine-level productivity is shaped by unobserved factors that also impact the closing decision (*omitted variable bias*), e.g., whether a mine has refinement plants (e.g., power plant) attached, the economic potential of a region, as well as local differences in industrial policy. Ex-ante, the direction of the OLS bias is unclear. A better future economic potential would likely imply higher productivity and could ease structural change, so that exit is not postponed ($\hat{\beta}_{OLS} > \beta$). Good policymaking could increase mine-level productivity and delay exit ($\hat{\beta}_{OLS} < \beta$).

I address the endogeneity problem by means of an instrumental variable approach. A mine-level instrument needs to be a relevant shifter of productivity, should not correlate with unobserved drivers of the exit decision, and should not have a direct effect on closures. I use geological conditions which affect mine productivity as an instrument. Geology, i.e., the nature of below-surface sediment layers, however, should not directly affect business leaders' decision of whether to close a mine or not (the outcome variable). I rely on three geological measures of coal degradability - illustrated in Figure 7 - which affect mine-level productivity. First, mines' *coal angle* (see box 1. in Figure 7), i.e., the coal layer's steepness. The higher the coal angle, the more difficult machinery usage and construction work of tunnels. I use the share of coal deposits with a coal angle of up to 25 degrees.

Second, the depth of the coal layer, the so-called *marl thickness* 2.. Marl is the sediment layer between the surface and the coal layer. The thicker this layer, the higher the set-up costs of a mine. Mines, therefore, were only profitable to build in thick-marl regions when they were more productive to break even. Also, the necessary technology to break through the marl layer was only available by mid-19th century, so that mines in thick-marl regions typically are younger with wider tunnels. That makes the adoption of large-scale machinery more feasible. Third, the *seam thickness* 3.. Thicker coal layers give a higher return on machinery usage.

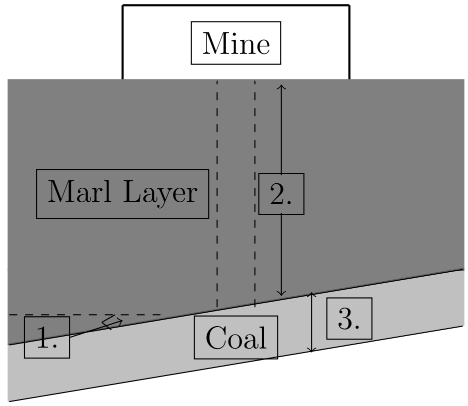


Figure 7: Sketch of a Mine and Coal Degradability Factors

In Panel (a)-(c) of Figure A9 in the Appendix, I show that all three measures strongly correlate with labour productivity (coal output per worker shift) and TFP. To combine all three measures into one IV, I conduct a principal component analysis which joins the isolated, independent variation from all three variables. The constructed variable is a strong predictor of productivity (panel (d)). By assumption, the IV needs to satisfy random assignment holding mine characteristics fixed (i.e., conditional independence) and should only affect exit through the productivity channel (i.e., exclusion restriction). Conditional independence is ensured by controlling for the main sources of mine heterogeneity in exit decisions and not including any kind of mine-specific factors beyond geology as part of the instrument. With regard to the exclusion restriction, the IV should not affect exit decisions beyond shifting mine-level productivity. If the geology affected, for example, not-included local industry structure, this would invalidate the IV. Figure A10 in the Appendix provides conditional correlations of the IV with mine-specific measures of ownership, vertical relations, transportation networks as well as local economic strength and industry composition. The IV is not significantly correlated with these measures.

Lastly, there is no reverse effect of productivity on geology, i.e. firms of heterogeneous productivity do not select into different geology. Mines have mainly been established in the 19th century when vertically integrated industry firms primarily chose to quarry for coal in the nearest possible coal field. Also, geology as a main driver of machinery productivity has been a less important productivity determinant in the times of labour-intensive work back then (Gebhardt 1957).

Intensive Margin. To analyze how firms adapt their production after the *RV*, I examine the

RV's effects on mine-level outcomes in a difference-in-differences setup. I compare surviving mines of firms, that heavily took up the policy, to less-exposed firms and non-uptakers, before and after the policy. I estimate a dynamic, continuous exposure difference-in-differences regression:

$$Y_{it} = \alpha_i + \beta_{dt} + \sum_{\tau,\tau\neq 1962} \delta_\tau [RV\ Exposure]_j \times 1[Year = \tau]_t + u_{it} \tag{9}$$

where Y_{it} is an outcome of mine i owned by firm j in year t. Mine and coal district-year fixed effects are given by α_i and β_{dt}. $[RV\ Exposure]_j$ is a treatment variable that is the share of pre-policy capacity which owner j of mine i closed through the RV. If a firm shuts down all its mines, the variable will be 1. If it did not shut down a single mine, it is 0. While firms actively decide on their exposure level, the timing and size of this shock is exogenous from the perspective of a surviving mine. Accounting for the rich variation in the uptake and exposure to the policy in a continuous treatment variable is more precise than a binary treatment of policy uptake or not. τ mostly ranges from 1956 to 1971 but the window can narrow for data availability reasons for some outcomes. To only capture spillovers to the unaffected mines, I do not include the closed mines in the regressions. As they were only operating before the policy-induced closures, they would not contribute to the identification of changes from before to after the policy anyway.

I identify a causal effect of the policy uptake under two assumptions. First, the parallel trends assumption implies that mines of firms with different exposure levels would have evolved similarly absent the policy. I will provide suggestive evidence for this by looking at the pre-trends. This also is an implicit test for potential reverse causality. In particular, if changes in mine outcomes led to the uptake of the policy, this would cause an upward or downward pre-trend.

Second, the stable unit treatment variable assumption (SUTVA) has to hold. It requires that the outcome and treatment status of one mine is unaffected by the treatment status of other mines. In my setting, however, it could be the case that there are spatial spillovers between treated and untreated mines, so that treatment effects should be interpreted as relative effects between treated and untreated mines. For example, the closure of a mine affects non-treated mines through a potential inflow of workers. We later on provide insights that spillovers across firms in space are limited mitigating the SUTVA concerns.

In the last step, I further explicitly estimate the effect of the policy on misallocation as reallocation could explain productivity changes in the industry, too. Misallocation is usually identified by showing that there is a negative or only weakly positive correlation between productivity and market share (Baily et al. 1992, Bartelsman et al. 2013, Griliches & Regev 1995, Melitz & Polanec 2015, Olley & Pakes 1996, Pavcnik 2002). In the triple-difference analysis, I can analyse how the policy affects the relation between market share and productivity in treated firms:

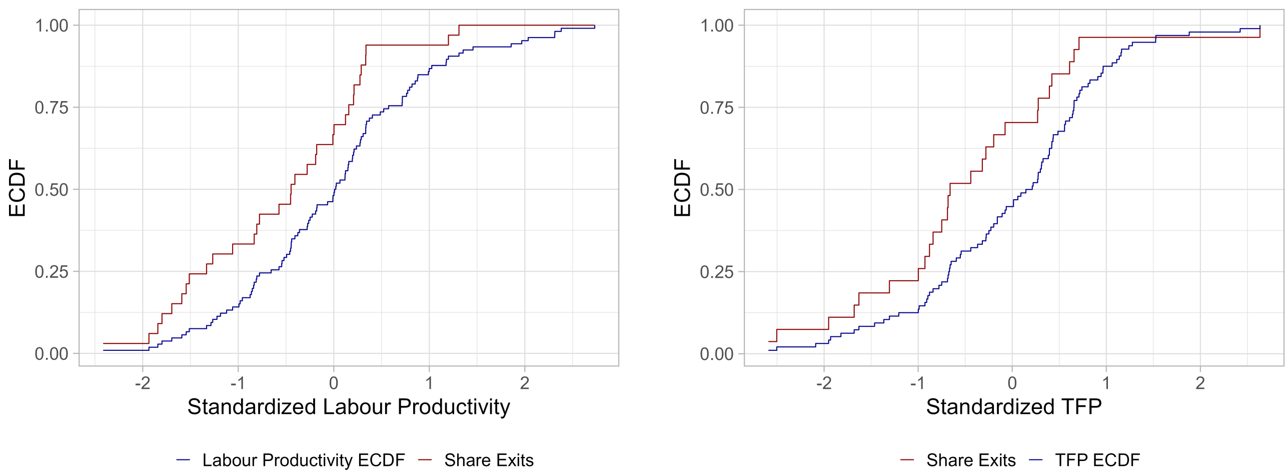
$$s_{it} = \alpha_i + \beta_{dt} + \sum_{\tau,\tau\neq 1962} \delta_\tau Prod_{it} \times [RV\ Exposure]_j \times 1[Year = \tau]_t + \Gamma'_{it}\zeta + \epsilon_{it} \qquad (10)$$

where s_{it} is mine i's market share in period t. Γ_{it} is a matrix including the further variables and interactions of the triple-difference model. An increasing relation between productivity and market share would be expressed by positive values for δ_τ if $\tau > 1962$.

Selection into Treatment. Mines differ in their characteristics which impact their owners' decision to exit or not. Hence, treated and non-treated mines of different $[RV\ Exposure]_j$ might structurally differ. I provide a comparison of both groups in Table A4 in the Appendix. There, I regress the treatment status on a number of mine-level variables. I show that there are almost no differences. The only robust disparity is that treated mines belong to bigger mining firms. This is by construction as only mines of multi-mine firms can be treated because at least one mine of the same firm has to exit. Hence, I cautiously interpret these results as in favor of the treated mines being close to representative of all surviving mines. I later on provide robustness checks that my main results also hold for a subsample of only multi-mine firms.

5 Results

Recall that we are interested in the productivity effects of the policy. In this section, I provide results on three channels via which the policy affects industry-wide productivity: First, indeed, the policy closes especially low-productivity mines. Second, firms reallocate production of closed mines to more productive, remaining mines. Third, firms increase within-mine productivity of



(a) Labour Productivity

(b) TFP

Figure 8: Empirical Distribution Function of Productivity and Policy Uptake (Exit)

remaining mines after closing one of their other mines. I consecutively discuss these channels in the subsections below. I also mention underlying mechanisms and stock market responses.

5.1 The Effect on Exit

First, I test the policy's attempt to force unproductive mines out of the market. Figure 8 descriptively plots the empirical distribution functions of productivity (blue) against the cumulative policy uptake, i.e., exit, across mines (red). Productivity first-order stochastically dominates cumulative exit. Hence, there is a negative correlation between productivity and exit in the sample. Table 1 investigates the relationship between exit and mine-level productivity. Panel A provides the OLS and Panel B the IV results.

Panel A reveals a significant negative relationship between exit and both productivity measures. A one standard deviation increase in labour productivity or TFP implies a reduction in the likelihood of exit by 14 and 23 p.p. respectively. This is robust across (columns (1) and (4)) and within firms (i.e., including firm fixed effects, columns (2) and (5)). Lastly, in columns (3) and (6), I control for additional variables likely affecting exit. I highlight two of the variables in the regression table: (i) a dummy indicating that a mine had an above-median share of cancelled shifts due to insufficient demand and (ii) a dummy indicating that a firm has closed a mine which produces the same coal type as mine i through the policy. Insufficient demand is a driver of exit and the policy uptake becomes less likely if a firm already closed another mine producing the same type of coal. The relation between productivity and exit is unaffected by the inclusion of the controls.[12]

In Panel B, I then examine the causal relationship using the preferred IV model. I instrument productivity with the 'coal degradability' IV including the information about a mine's geology. The first stage F-Statistic is above the threshold of 10 in all specifications, i.e., the IV is relevant. The IV results show a negative causal effect of productivity on exit about twice as large as the OLS coefficients. Additionally, I provide results on marginal costs (based on the production function approach) instead of labour productivity or TFP in Table A5 in the Appendix. Marginal costs also take into consideration input prices and not just the efficiency of inputs. The table also provides the IV results when using the three geology dimensions as IV individually.

To judge the effect of this positive selection of mines, I compare the average, weighted labour productivity of the remaining mines with the overall sample of mines right before the policy uptake. I find that the remaining mines have a 17.4% (7.9%) higher labour productivity (TFP). Exit therefore increases industry-level productivity by 3.1% (1.5%).

I assess how close the observed selection is to an optimal selection benchmark, i.e., exit ordered by productivity rank. I calculate the productivity gain from the exit of the least efficient mines which sum up to the same exit output volume as actually observed. This exit, for example, would have increased industry-wide productivity by 4.8% (3.3%) with respect to labour productivity (TFP). Hence, the observed selection worked arguably well given that productivity is not the only factor driving the exit decision.

Finally, the finding of relatively efficient exit orders adds to the empirical literature on exit orders and industry shakeout (Gibson & Harris 1996, Hünermund et al. 2015, Klepper & Simons 2000, 2005, Klepper & Thompson 2006, Lieberman 1990, Takahashi 2015). Theoretical work has shown that exit in multi-entity firm environments might be inefficient as smaller firms can commit to staying in the market given a decreasing demand for a longer time (Fudenberg & Tirole 1986, Ghemawat & Nalebuff 1985, 1990, Whinston 1988).

[12] Also including further controls such as the mine age does not affect the results.

Table 1: Selection of Plants into *RV* by Productivity

	1[Closure via RV]$_i$					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: OLS						
Standardized LP$_i$	-0.183^{***}	-0.210^{***}	-0.198^{***}			
	(0.033)	(0.036)	(0.042)			
Standardized TFP$_i$				-0.155^{***}	-0.261^{***}	-0.206^{***}
				(0.055)	(0.068)	(0.067)
1[High Cancelled Shifts]$_i$			0.458^{***}			0.384^{**}
			(0.125)			(0.146)
1[Closure of Same Coal Type Mine]$_i$			-0.513^{***}			-0.379^{***}
			(0.085)			(0.101)
Panel B: Instrumental Variable						
Standardized LP$_i$	-0.528^{***}	-0.483^{***}	-0.358^{***}			
	(0.162)	(0.139)	(0.129)			
Standardized TFP$_i$				-0.287^{***}	-0.409^{***}	-0.358^{***}
				(0.065)	(0.109)	(0.129)
1[High Cancelled Shifts]$_i$			0.461^{***}			0.331^{**}
			(0.116)			(0.164)
1[Closure of Same Coal Type Mine]$_i$			-0.470^{***}			-0.243
			(0.133)			(0.155)
F-Statistic First Stage	*10.63*	*12.46*	*10.96*	*50.78*	*33.56*	*24.89*
Mining District FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm/Owner FE	No	Yes	Yes	No	Yes	Yes
Observations	106	106	97	96	96	96

Note: Significance levels of 10%, 5% and 1% are denoted by *, ** and ***. Labour productivity is averaged over 1959-1961. TFP is averaged over 1960-1961 (no data for 1959). Standard errors are clustered at the firm/owner level.

5.2 Output Reallocation

Output Spillovers Within-Firm. Second, the policy could have affected industry productivity through other channels beyond exit. In particular, firms could have reallocated their production across their mines after a mine closure. I first look at how the policy uptake affected the output of a firm's remaining mines by estimating equation (9) with logged output as the outcome. The left panel of Figure 9 shows that the output of mines with mean treatment exposure expands by around 10% (coefficients are multiplied with the mean $[RV\ Exposure_j]$ of mines with positive exposure) relative to mines of non-treated firms. Hence, firms close mines through the policy but increase production in the remaining mines. As increasing production needs improved infrastructure beforehand and given that not all exits were immediately in 1963, these spillovers occurred a few years after the policy. To prove that the output growth is not driven by an increase in coal capacity or mergers and acquisitions, I show that the coal field size of mines and the probability of a coal field merger do not change with the policy (see left panel of Figure A7 in the Appendix).[13] Instead, I show that more work is done within the same mine borders. For example, more seams, i.e., coal layers, are worked on within the same coal field (right panel).

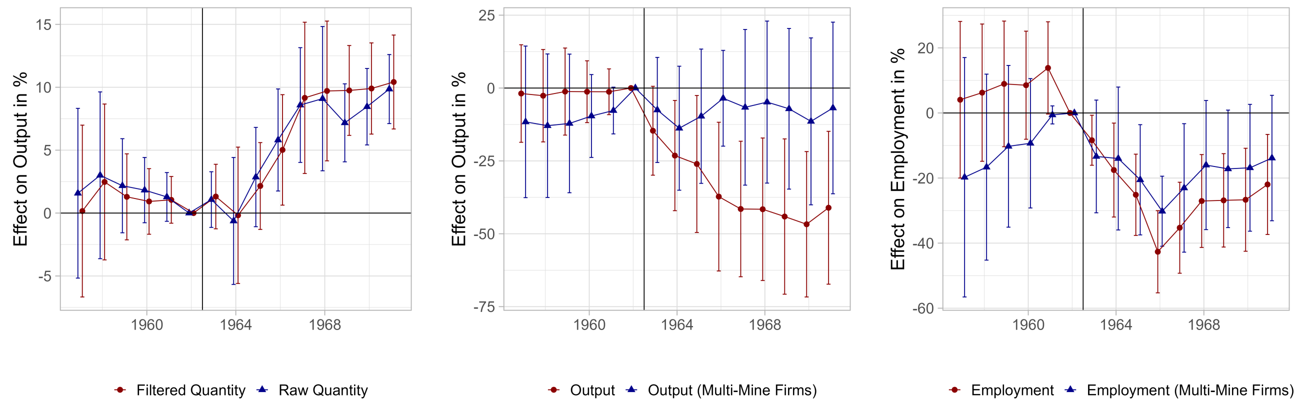
To understand the relative size of the output spillovers in remaining mines in comparison to the closed capacities, I run an analysis on output at the firm level before and after the policy (middle panel of Figure 9), i.e., a difference-in-differences regression in the style of equation (9), where I interact $[RV\ Exposure_j]$ with year fixed effects conditional on firm and coal district-year fixed effects. Firm-level output is normalized to 100 in 1962. For a one percentage point increase in the exposure, i.e., a coal firm officially closed one p.p. of the pre-policy output and earned the respective subsidies, a coal firm effectively only reduces output by 0.34 p.p. on average over the period 1963 to 1971 with a maximum effect size of 0.45 p.p. right after the policy. Thus, more than half of the closed volume is recovered in the remaining mines of treated firms. Firms earn an effective closure subsidy of more than twice the official 25 DM/tonne. That the effect is not larger than 0.45 p.p. even right after the policy indicates that firms shift mines and output to other mines very soon after the closure.

I then look at a subsample of only multi-mine firms (red line). Single-mine firms by construction cannot shift production to other mines of the same firm after a closure. I find that multi-mine firms do not decrease their production volume at all.

Doing the same for employment instead of output, I show that per 1 p.p. of closed capacity, the net employment loss is only 0.33 p.p., supporting the spillovers described above. Again, multi-mine firms show a smaller but significant effect. The unchanged output volume next to lower employment already hints at potential gains in productivity in treated firms.

Heterogeneity in Mine-Level Output Reallocation. For policymakers, it is essential to un-

[13]Figure A8 in the Appendix shows how coal fields are distributed between coal firms as of 1962.



(a) Mine-Level Output Spillovers (b) Firm-Level Output Spillovers (c) Firm-Level Worker Spillovers

Figure 9: Existence and Scale of Spillovers Within Uptaker Firms

Note: Left panel is based on equation (9). Middle and right panels based on equation (9), too, however at the firm level. For left panel: Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. Regressions in middle and right panels weighted by 1961 firm-level output to account for firm-size differences. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.

derstand what triggers output reallocation. I perform heterogeneity analyses along multiple mine dimensions. I subsequently show the policy induced reallocation to large, efficient mines.

First, I study whether mines with high productivity have the strongest output increases due to the policy. The first panel of Figure 10 shows that, indeed, mines that had an above-median labour productivity or TFP in the pre-policy year 1962 face the strongest output increase. Above-median mines of treated firms are 31% (16%) more productive in terms of labour productivity (TFP) than closing mines. Given that about half of the closed capacity (i.e., about 10% of the industry production) is reallocated towards these productive mines (see Figure 9), this reallocation increases industry-wide labour productivity (TFP) by 3.2% (1.7%).

Second, I show that output increases especially in mines that had some form of coal refinement plant attached, i.e., either a cokery or an electricity plant. Cokeries and electricity plants were stable consumers of coal, in contrast to declining coal demand for household and industry consumption. This indicates that the policy led toward a shift of the business model along the value chain and to reallocation to more secure and less volatile demand segments.

Beyond that, I investigate further dimensions of heterogeneity to explain the underlying reasons for reallocation. Reallocation takes place towards larger mines (in terms of pre-policy output) which on average are also more productive (see Figure A11 in the Appendix). I further show that spillovers are especially strong for mines that experience exit of mines from the same firm nearby (2.5 or 5km radius). Hence, the geographical distance matters[14]. Also, output expansions are especially strong in larger firms with a larger number of mines.

Lastly, I show that output increases are largest for mines with a higher number of worker flats per capita, which have been operating for the shortest time, and with a low share of apprentices right before the policy introduction. Housing availability is necessary to be able to increase the number of workers. Younger mines on average have a higher mechanization rate. A lower share of apprentices implies a higher input quality, so that reallocation takes place to mines with better labour input. But also, the costs of laying off workers increase with age, so that reallocation towards mines with a lower share of apprentices can also be explained by the higher opportunity costs of not shifting capacities to such mines. All these heterogeneity analyses prove that reallocation takes place to productive, large mines with substantial potential to increase production further.

As a second piece of evidence that reallocation towards more productive mines took place, I conduct an analysis motivated by productivity decompositions in the fashion of Olley & Pakes (1996) and others. These papers argue a reduction in misallocation is achieved when the covariance between market share and productivity increases, i.e., more productive firms produce more in relative terms. I convert this intuition to an empirical test in a difference-in-differences framework following equation (10). Figure 11 shows that after the policy, indeed, the relationship between productivity and market share became stronger. A one standard deviation increase in productivity increases the market share of a mine with an average exposure by 0.25 p.p. (or 15%) after the policy.

Adjustments in Input Decisions. The increase in output raises the question of how input choices changed in policy-uptaking firms after the policy. For this, I study labour and capital. Figure 12 presents the policy uptake's effect on the remaining mines of a treated firm. In line

[14] As an underlying channel, I document that especially worker flows from closing mines to surviving mines take place in response to exit. Figure A12 in the Appendix shows that mines that had exit from a different mine of the same firm nearby experienced an inflow of educated workers. The share of experienced workers from closed mines coming over to the surviving mine nearby (2.5km radius) increases by 40 p.p. for three years after the policy. Mines with closures farther away do not experience an increase in educated workers delivering another reason for fewer spillovers to such mines.

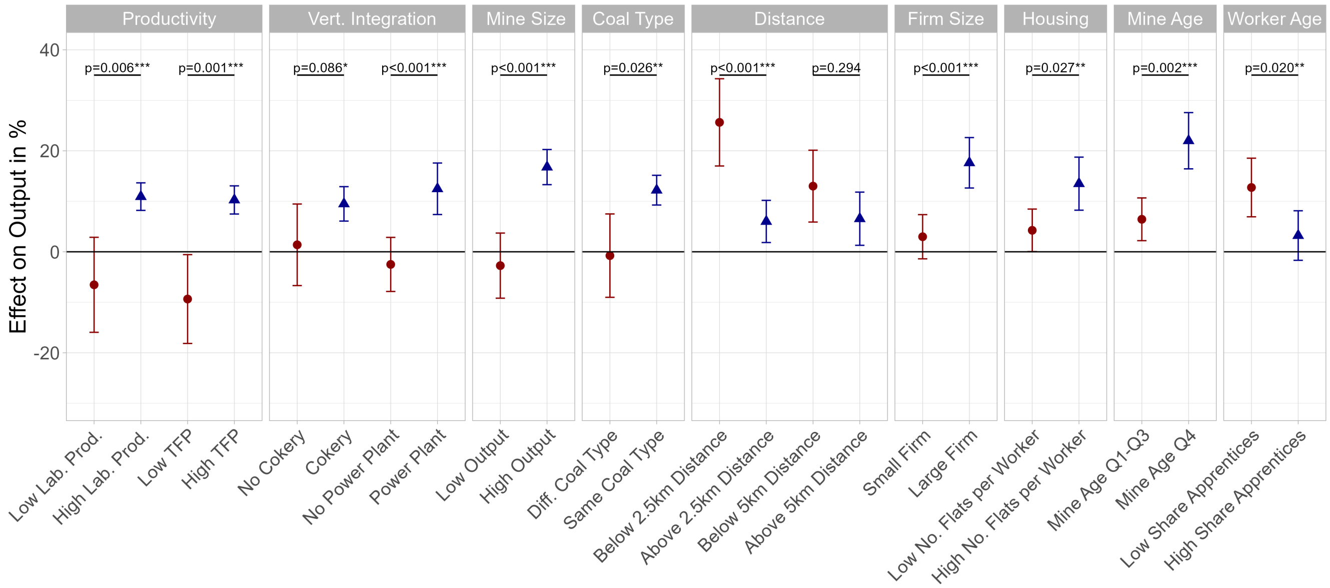


Figure 10: Reallocation along Dimensions of Heterogeneity

Note: Estimates come from a triple-differences estimation based on equation (9) where I pool all post-treatment years after the majority of exits occurred, i.e., after 1965. Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.

with the documented output increase in treated mines, I find that capital, as well as employment, rise strongly after the policy. The power of machinery used in the mine increased by up to 20% until 1971 for a mine of average policy exposure (see left panel of Figure 12). Also, employment of miners as well as non-miner employment rose by up to 8% a few years post-policy (see right panel of Figure 12). I also show that the capital intensity, i.e., the machinery power per worker in the mine, increases significantly by up to 10%, so that the policy led to a more machinery-intensive production process.

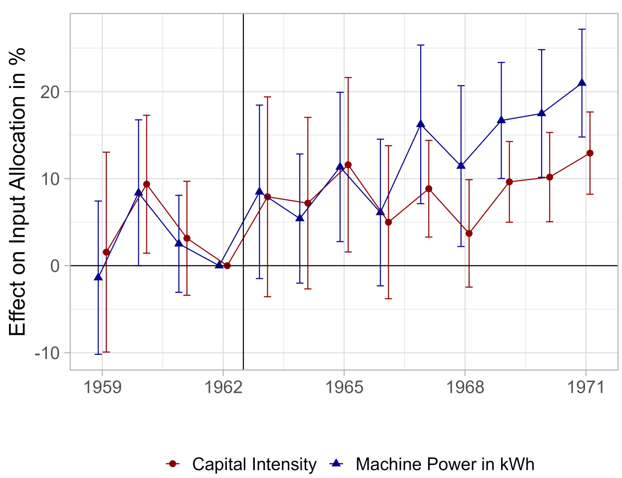
5.3 The *RV*'s Effect on Dimensions of Productivity

I showed that the policy leads to exit of unproductive mines and to reallocation towards large, productive mines. These changes in the industry competition raised average productivity. Now, I will further show that the policy fostered within-mine productivity growth.

Productivity, Markups, and Marginal Costs. The policy targeted increasing industry-wide

Figure 11: Effect on Reallocation

Note: Based on equation (10). Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. This plot documents how the policy affects the relation between productivity and market share. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.



(a) Capital

(b) Labour

Figure 12: Effect on Input Consumption

Note: Based on equation (9). Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. These plots document how the policy uptake affects the input allocation of remaining mines of treated firms. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.

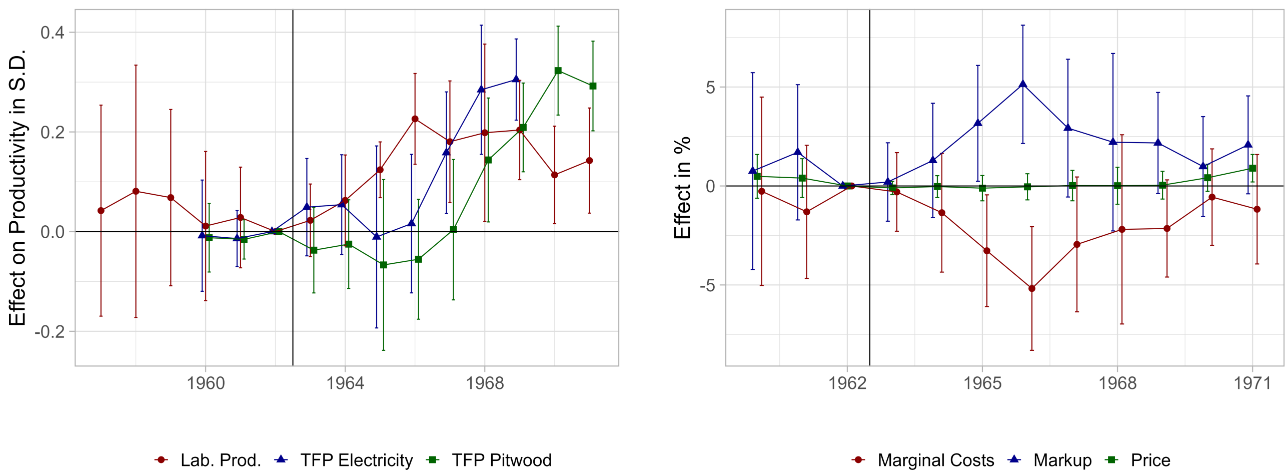
productivity through the exit of unproductive mines. Productivity gains can also stem from within-mine productivity growth which I examine subsequently. The left panel of Figure 13 shows a strong and persistent increase in labour productivity (TFP) after the policy in mines of policy-uptaking firms by up to 0.2 (0.3) standard deviations or 6.0% (7.3%) respectively for the mean exposure. For TFP, I present results based on two production function estimations as described in Section 4 - a Cob-Douglas production function with electricity (data until 1969 only) and a Leontief production function with pit wood. Hence, the policy led to strong productivity increases within mines that have sibling mines closed through the policy. Since not all mine closures occurred immediately in 1963, it is intuitive that the effects manifest gradually over time.

Note that the treated mines made up about half of the production in 1971, so that the 6.0% (7.3%) increase in labour productivity (TFP) translated to an about 3% (4%) increase in labour productivity (TFP) in the industry.

Productivity gains can come from investments or economies of scale. To show that these productivity gains are not just caused by potential economies of scale, i.e., the increase in output as shown in Figure 9, Figure A13 in the Appendix controls for mine-level output as a 'bad control'. The treatment effect on productivity is only partially explained by output changes, motivating that investments could play a crucial role for the arising productivity gains. I look at this mechanism later on in Section 5.4.

I further examine how the policy affected marginal costs and markups. The right panel of Figure 13 shows that marginal costs drop in response to the policy - at least temporarily. Marginal costs on average decrease by 1.5% which translated to cost savings of approximately 400 million DM over the nine post-effect window years. Hence, costs savings exceed the overall premium payments which the state paid through this policy. As expected due to the price setting in the retail organizations, prices do not change with the treatment.

Interestingly, TFP increases in the long-run but marginal cost savings are only temporary. As I will show later on, this is driven by increasing mine-level wages in treated mines in the long-run, which I use for the markup calculation as labour is the variable input - see point 'Markdown' in Section 6. There, I also show that when using electricity as material input, marginal cost gains



(a) Productivity

(b) Markups and Marginal Costs

Figure 13: Effect on Mine-Level Productivity, Markups and Marginal Costs

Note: Based on equation (9). Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.

seem to be more persistent over time.

Survival. Given that mines increase productivity, I examine whether these investments lead to longer survival. Figure 14 plots the effect of the policy on the likelihood of not having exited yet. Exposed mines are on average 10 p.p. or 21% more likely to survive for three decades post-policy. For mines that are treated with more than the median $[RV\ Exposure_j]$, the effect is even stronger (20 p.p. or 42%) and significant for a longer time period. The increase of 10 p.p. translats to an lifespan extension of 5.7 years for mines of policy-uptaking.

Productivity Dispersion. Given that coal firms used the subsidy to reallocate production to their largest, most efficient mines, it is an open question what happens to their weaker mines. To unveil heterogeneous effects on productivity for mines with different ex-ante productivity level, I estimate (unconditional) quantile treatment effects of the policy along the productivity distribution in a similar fashion to Chen et al. (2022). I estimate the counterfactual distribution of productivity based on the distribution regression method by Chernozhukov et al. (2013). It obtains the counterfactual distribution (i.e., productivity of treated mines absent treatment) by estimating the pooled

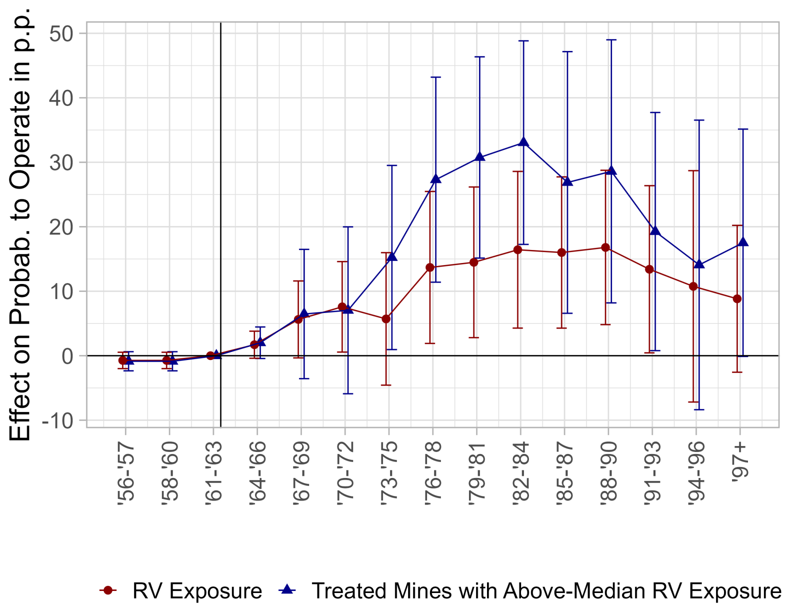
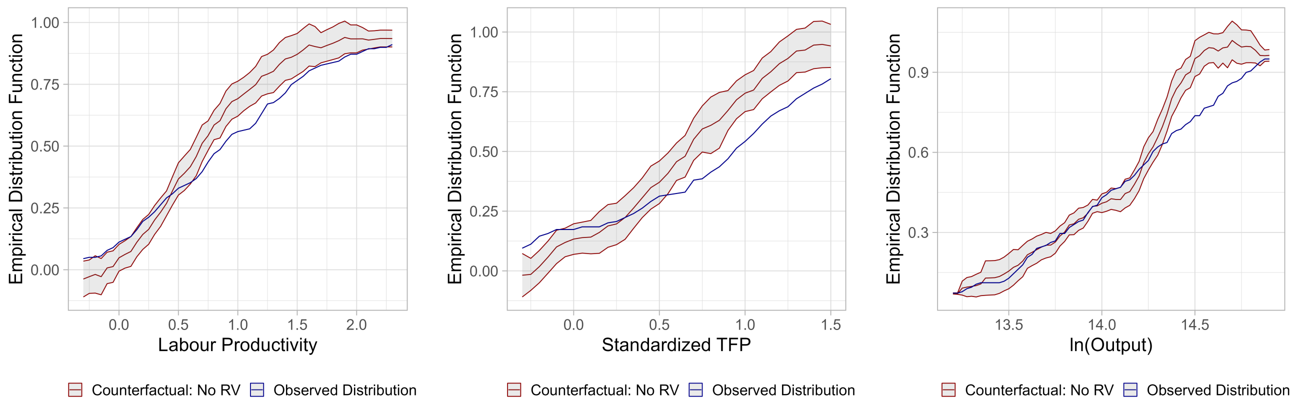


Figure 14: Effect on Mine Survival

Note: Based on equation (9) and a balanced mine-year panel. For blue line: Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.

version of the difference-in-differences equation (9) with an adapted outcome variable. It estimates the effect of the policy exposure on a dummy that will be one if a mine-year observation has a productivity below a certain cutoff value. Adding the estimated treatment effect to the empirical distribution function of observed productivity then gives the value of the counterfactual distribution at this particular cutoff value. Repeating this for many cutoffs gives the full counterfactual distribution function. The first two panels of Figure 15 show that the within-firm spillovers are associated with productivity increases at the upper tail of the productivity distribution and a negative change at the left tail.[15] Hence, already productive mines become even more productive and unproductive mines deteriorate relative to more productive mines. Importantly, this productivity dispersion is based on the sample of surviving mines. As shown in the right panel, this is driven by the fact that the policy leads to output increases in very large mines. As Syverson (2004, 2011) argues for revenue-based TFP, productivity dispersion correlates with increasing market concentration and is a measure of inefficiency. A similar argument holds for physical TFP as I use in my

[15]This fits the distributional effects in Behrens et al. (2020) who show for many sectors that unproductive firms produce too much from a welfare point of view.



(a) Labour Productivity (b) TFP (c) Output

Figure 15: Distributional Effect of *RV* Policy

Note: Based on distribution regression approach by Chernozhukov et al. (2013). Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.

analysis.

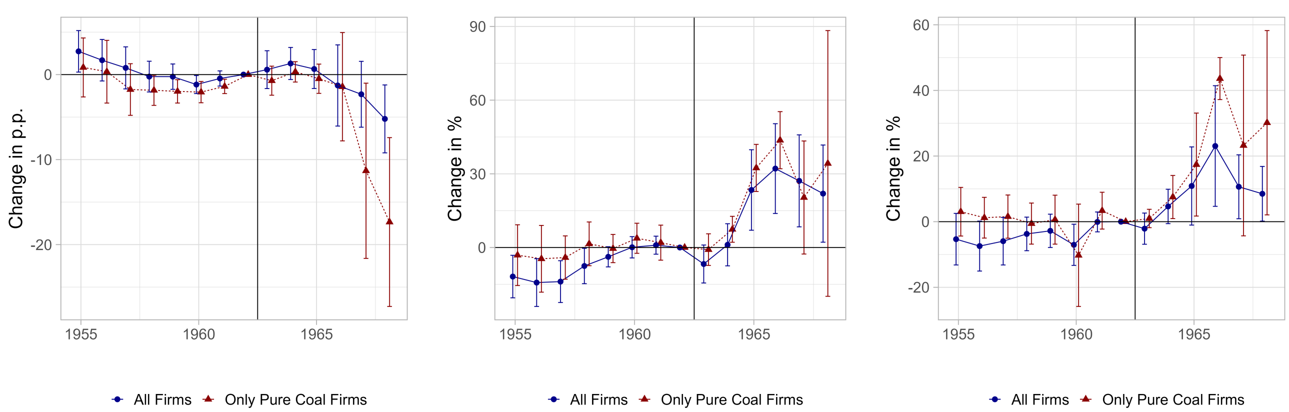
With regard to reallocation, panel (c) shows that the policy led to a growth in mine size of formerly already very large mines. This is further support for reallocation towards large, efficient mines. Hence, the policy set up very large, productive mines endogenously. Absent the policy, the largest mine of treated firms would have been smaller than one fourth of the treated mines after the policy. Figure A14 in the Appendix runs the distributional analysis for mine-year market shares and shows that the policy-induced reallocation was a main driver for the existence of mines with more than 2% market share. The policy more than doubles the share of mines with at least 2% market share.

5.4 Mechanisms

In this subsection, I study the underlying drivers of reallocation and productivity gains. I find that the subsidies earned alleviate financial constraints. That allows firms to invest in their infrastructure and technology adoption.

Financial Constraints. While I showed that output spillovers and productivity growth took place in response to the policy, it remains unclear what exactly triggered this transformation. Is it that mines that receive more closing payments or are more financially constrained before the policy respond more strongly (*financial constraints*) or is it that the found effects stem from other mechanisms such as general spatial, across-firm spillovers from mine closures (*local spillovers*)? I examine these channels subsequently.

First, I use firm-level financial data to test whether financial constraints are lifted by the policy. Figure 16 presents the following for a sample of all stock-market listed firms (blue) and firms that have coal production as only business (red): Firms with a higher exposure to the policy, i.e., a higher share of closed capacity, experience a larger drop in their debt ratio (debt over the sum of debt and equity) by up to 15 p.p. (see Panel A). The reduction in financial constraints also simultaneously translates to higher stock values and dividends (Panel B and C), i.e., financial markets expect firms' new financial potential to restructure their production to result in improving firm result metrics.



(a) Debt Ratio (b) Stock Values (c) Dividends

Figure 16: Effect on Debt Ratio and Stock Market Evolution

Note: This plot documents how the policy uptake affects firm-level stock values, dividends, and the firms' debt ratios. Right panel based on equation (9) at the firm level. Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported. Sample ends in 1967 as the majority of firms merged to the agglomerate Ruhrkohle AG afterwards.

I further provide support on the financial constraint mechanism in Table 2, where I explicitly test the role of financial constraints for the extent of reallocation due to the policy. Panel A gives the baseline results from Section 5, i.e., surviving mines of policy-uptaking firms increase output, employment, and capital. In Panel B, I add an additional difference-in-differences interaction, that gives the policy exposure measured in the net premium per remaining tonne of production ($[Net\ Exposure\ in\ DM_j] \times 1[Year > 1965_t]$) instead of the output-weighted measure, $[RV\ Exposure_j]$. The net premium accounts for the heterogeneous payments to competitors for their closures and also considers different closure subsidies depending on whether the closure belonged to the early part of the policy (*Vorausaktion*) or not. The firms of 43% of the mines in the sample are net receivers from the policy. Hence, here I run a horse race of the exposure to the policy measured in the share of closed quantity, $[RV\ Exposure_j]$, versus the actual financial exposure, $[Net\ Exposure\ in\ DM_j]$. It can be seen that only the monetary exposure matters for the reallocation effects. Hence, the net amount of subsidies received is driving the reallocation process. The more money earned per remaining unit of production, the stronger the reallocation and output increase.

In Panel C, I explicitly test whether the lifting of financial constraints matters for the policy response. The policy-induced increase in input usage is stronger for those mines that belong to firms with a higher debt ratio (debt capital divided by overall capital), i.e., that were more financially constrained, in 1961 right before the policy.

In Panel D, I show that the effect is not driven by the fact that output spillovers just reflect spatial spillovers between mines of the same firm or across firms. The existence of closed mines of other firms nearby has no explanatory power across firms, only the exposure of the mines' own firm matters.

Investments, Infrastructure, and Technology Adoption. I subsequently show how the lifting of financial constraints mapped into productivity gains by leading to more investments, an improved mine infrastructure, and a higher technology adoption. In the context of mines, productivity increases require investments, e.g., new tunnels to rich coal layers. While such construction work is very costly, firms could use the earned closure premium to invest.

The left panel of Figure 17 documents that the remaining mines of uptaking firms on average slightly increase their mine depth by 4%. This effect is especially driven by very deep mines. The

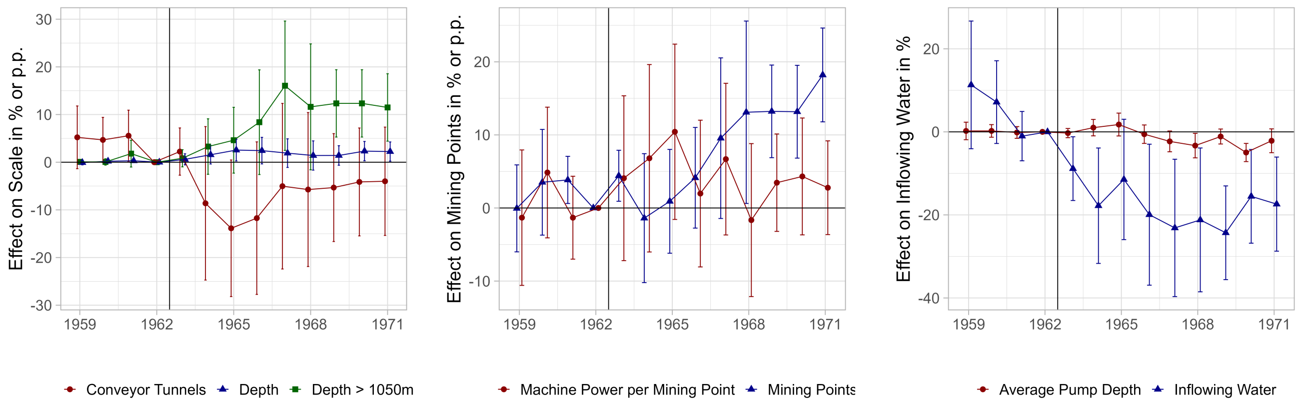
Table 2: Mechanism

	log(Output) (1)	log(Miners) (2)	log(Machinery) (3)
Panel A: Baseline			
$[RV\ Exposure_j] \times 1[Year > 1965_t]$	0.318***	0.299**	0.376***
	(0.100)	(0.111)	(0.139)
Panel B: With Net Exposure			
$[RV\ Exposure_j] \times 1[Year > 1965_t]$	0.091	0.010	0.121
	(0.128)	(0.151)	(0.124)
$[Net\ Exposure\ in\ DM_j] \times 1[Year > 1965_t]$	0.005***	0.006***	0.005**
	(0.001)	(0.002)	(0.002)
Panel C: Financial Constraints			
$[RV\ Exposure_j] \times 1[Year > 1965_t]$	−0.215	−2.227*	−2.084*
	(1.042)	(1.185)	(1.013)
$[RV\ Exposure_j] \times 1[Year > 1965_t] \times [Debt\ Ratio_j]$	0.834	4.004**	3.628**
	(1.643)	(1.926)	(1.613)
Panel D: Local vs. Within-Firm Spillovers			
$[RV\ Exposure_j] \times 1[Year > 1965_t]$	0.303***	0.283***	0.387***
	(0.098)	(0.103)	(0.123)
$1[Mine\ Closure(s)\ Other\ Firm\ [0, 2.5)\ km_j] \times 1[Year > 1965_t]$	−0.030	0.070	0.064
	(0.061)	(0.065)	(0.097)
$1[Mine\ Closure(s)\ Other\ Firm\ [2.5, 5]\ km_j] \times 1[Year > 1965_t]$	−0.065	−0.039	0.066
	(0.044)	(0.051)	(0.064)
Mine FE	Yes	Yes	Yes
Coal District-Year FE	Yes	Yes	Yes
Observations (Panel A, B & D)	1,012	1,012	861
Observations (Panel C)	633	633	534

Note: Based on equation (9) with pooled post-dummy with years after the majority of exits took place, i.e., 1965. Significance levels of 10%, 5% and 1% are denoted by *, ** and ***.

probability that mines have a maximum depth of over 1,050m (75th percentile) is increasing by 10 p.p. after the policy. On average these deep mines are younger and more productive, so that investments might have a higher return. Deepening a mine is very costly, can take several years, and can be seen as a large-scale investment into the infrastructure of a mine.

Moreover, the number of conveyor tunnels, i.e., vertical tunnels through which coal is brought to the surface, is unaffected. This means that current mines are extended within the already existing



(a) Infrastructure Investments (b) Capital Investments (c) Water Management

Figure 17: Effect on Measures of Investments

Note: Based on equation (9). Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.

mine framework (e.g., increasing depth) instead of expanding the mine across its former borders or acquiring new, deep coal fields. The latter would most likely require new conveyor tunnels.

In line with this evidence on investments into the mine, the middle panel of Figure 17 shows that there is an increase in the number of mining points, i.e., the positions in the mine at which coal is quarried at the same time. Hence, within the mine, work is done at more locations. Setting up a mining point requires investments in its setup. Even though the number of mining points increases, the machinery power per mining point does not decrease. Hence, the infrastructure investments into the mine go hand in hand with more, well-equipped mining points.

The right panel shows that the amount of water flowing into the mine is reduced after the policy. As pit water is an important security threat, mines improve water management and worker safety. Also, the average pump depth falls. Mines pump water from nearer to the surface reducing the risk of flooding in deeper mine parts. In the Appendix, I provide further evidence of improved worker safety as the prevalence of accidents slightly decreases with policy exposure (see Figure A15).

Further, given the investments and increased machinery power, I investigate changes with respect to technological change. In the 1950s to 1970s, there was a major switch from manual, non-mechanized coal mining (i.e., workers with automatic hammers) to large-scale machinery usage.

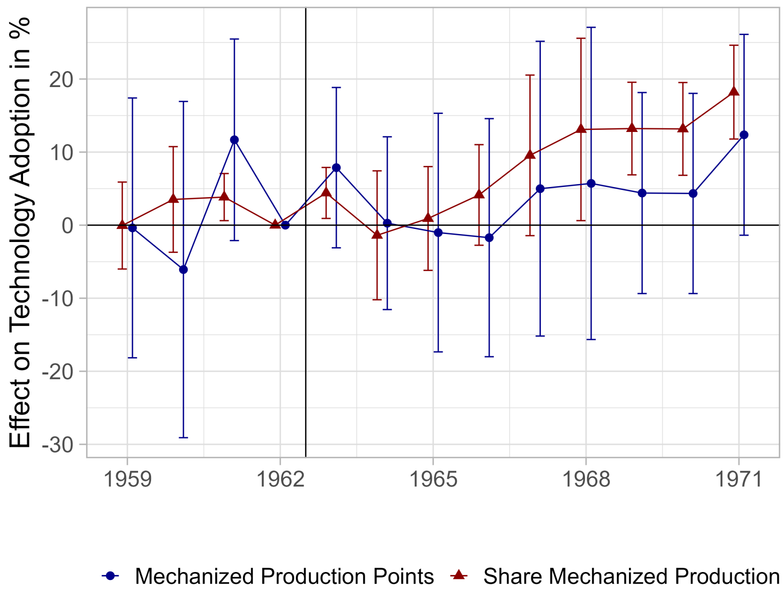


Figure 18: Effect on Mechanization

Note: Based on equation (9). Coefficients multiplied with mean [$RV\ Exposure_j$] for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.

While on average 33% of output was produced by mechanized production methods in 1957, this share increased to 90% in 1971. In Figure 18, I show that mines with a high policy exposure increase the share of mechanized production after the policy while the share of mechanized production points is unaffected. Hence, the policy led to an increasing use of new technologies such as cutting and pealing machines.

5.5 Spillovers to Downstream Cokery Industry

The mine-level production reallocation also has relevant effects on the downstream industry. I here focus on the important downstream industry that refines coal to coke, an intermediate good used in steel production. About 40% of the overall coal quarried is used in the coke production.

I study whether mines react to the policy by changing the type of coal they quarry. The type of coal is relevant as, for example, only some types of coal can be used for further refinement to downstream products such as coke. German cokeries became the most important demander for German coal in the 1960s and 1970s and offered stable demand given that coke could not

be substituted with oil. Hence, I study whether mines reallocate to producing fat coal, which is the coal type primarily used in cokeries. Figure A16 shows that there is an increase in fat coal output by about 10% while non-fat coal output is unaffected. Thus, treated mines are able to transform their production towards coal varieties which are more stable and less prone to demand fluctuations. Hence, the policy allows firms to reallocate production towards more stable markets. In line with the spillovers to mines with cokeries and the increasing output of coal that is useable for coke production, Figure A17 in the Appendix shows that exposed mines increased employment in their vertically integrated cokeries. Hence, reallocation has an impact on the employment decisions in the downstream industry, too. A back-of-the-envelope calculation suggests that treated mines increased their cokery employment by in total 350-400 jobs until the end of the 1960s.
At the same time, the right panel of Figure A17 provides no evidence of an improvement in cokery input quality and cokery efficiency. I proxy input quality with the share of volatile content in the coal used for coke production. The higher the share of volatile content, the more energy is lost in the cokery process. Cokery efficiency is measured as the output-input ratio of coke relative to coal, i.e., how much coke is produced from a unit of coal.

6 Other Potential Mechanisms

In this section, I discuss other potential mechanisms and show that they did not play a role.

Bargaining Power within Syndicate. Given the existence of joint retail organizations in this industry, one concern is that positive output spillovers to mines within the firm are a mechanical outcome of (legal) negotiations between firms. However, gained bargaining power from mine closures, which result in output increases, should lead to fewer shifts cancelled due to insufficient demand for treated firms relative to non-uptakers. Contrary to this, Figure A18 in the Appendix provides no evidence for this. Neither the extensive margin of cancelled shifts due to insufficient demand nor the intensive margin differ from mines of other exposure levels.

Local Demand and Long-run Contracts. First, a firm-specific or local demand shock could explain production increases in the remaining mines of exiting firms after the policy. However, all mines are located close by and likely are exposed to the same shocks. Also, joint retailing through the retail organizations has, by law, the purpose and mandate to smooth regional and coal type-specific fluctuations in demand across mines (High Authority 1956*a*).

Second, as the *RV* policy was unforeseen, one concern is that coal firms still have running long-run contracts to fulfill. Increasing output levels in the remaining mines could be one reason then to reach the necessary output levels. However, coal firms did not independently sign supply contracts with coal-demanding entities. Instead, they only sold coal through the retail organizations (High Authority 1965), making this concern obsolete.

Political Influence and Workers' Bargaining Power. Differences in regional politics and mine-level bargaining power of workers could drive my results. Political parties had different opinions on policymaking in the coal industry. While the governing Christian democrats and Liberals passed the *RV*, the only opposition party, the Social Democrats, was in favour of less severe, short-run employment drops (Bundestag 1959*b*, 1962). Therefore, I analyse whether local heterogeneity in political attitude affected firms' reallocation decisions - e.g., towards fewer layoffs. Using pre-policy voting results in the 1961 federal election at the county level, Figure A19 in the Appendix shows that there is no robust effect of political attitude on the reallocation decision.

To test whether spillovers are determined by workers' bargaining power, I exploit mine-level heterogeneity in workers' elasticity of labour supply. I use mine-level data on the share of foreign workers (so-called *Gastarbeiter*) which varied between 0 and 36% between mines. Foreign workers were less likely to leave the industry relative to native workers and it was difficult to organise them in unions (Seidel 2014). Figure A20 in the Appendix shows that there is no difference in the effect on inputs and outputs between mines with different *Gastarbeiter* exposure before the policy.

Output Quality. A different explanation for the diverging developments of mines over time is a change in the quality of products over time. Admittedly, coal is very homogeneous but perceived quality can vary. As this is unobservable or hard to measure, quality usually is proxied by input price data (De Loecker et al. 2016) or measures based on demand assumptions (Amiti & Khandelwal 2013, Khandelwal et al. 2013). As input prices, which vary at the mine level and over time, I only observe wages. Wages, however, can for example be distorted from bargaining differences. Instead, I use a measure that is specific to my setting, the amount of non-coal output quarried. The more non-coal output was quarried, the more likely it was that sold coal included non-coal content even after the washing process. By that, the energy content of coal supply is affected. Figure A21 in the Appendix shows that the amount of non-coal content is unaffected by the treatment.

7 Robustness Checks

Subsequently, I provide a number of empirical robustness checks.

Long-run Effects. In my main analysis, I restrict my sample to years up to 1971 because of other policy changes in the industry afterwards. For an extended sample until 1980, I show that the effects on output and input decisions are persistent (see Figure A22).

Production Function Approach. My TFP results rely on the correct specification of the production function. In Section 5, I provided results based on production function variants with either pit wood or electricity as the material input. In Table A7, I provide further robustness checks. Next to my baseline results in columns (1) and (2), I estimate a translog production function with pit wood as material in column (3) to flexibly account for potential substitution patterns between wood, labour and capital. In columns (4) and (5), I extend the time horizon beyond 1971 to 1980 and estimate the effect on TFP and labour productivity. In column (6), I take account of a potentially changing production function over time by adding two interactions of a time trend with the labour and capital variable respectively to the Leontief production function. This should also take care of potentially factor-biased productivity gains (De Loecker et al. 2020). Lastly, in column (7), I explicitly include a measure of technology adoption, i.e., the share of mechanized production at the mine-year level, as an input in the production function to account for factor-biased technology change. All of these specifications support that the policy led to productivity gains. Similarly, Table A8 shows that the extensive margin results, i.e., that productivity drives exit, are robust to the different TFP estimates.

Markdowns. Higher markups could also stem from endogenous input prices, i.e., for example, lower wages as workers face a reduced labour demand (Avignon & Guigue 2023, Morlacco 2019, Rubens 2023*b*). However, I show in Figure A23 of the Appendix that average wages increase in response to the policy in highly- relative to less-treated mines. While this does not eliminate the possibility of rising markdowns due to potentially an increasing marginal revenue product of labour in treated mines, this evidence limits the concern.

Additionally, I calculate markups based on the output elasticity from the Cobb-Douglas production function with electricity as material input. In electricity markets, market power is limited, i.e., one may assume identical input prices across mines. In Figure A24 in the Appendix, I show that the pattern of rising markups due to decreasing marginal costs is also evident in this robustness check - also if I restrict the sample to mines with their own power plants (self-suppliers). By construction, changes in markups over time should not stem from heterogeneous markdown developments for treated and non-treated self-suppliers.

Staggered Exit and Difference-in-Differences with Continuous Treatment. While all firms had to decide whether to close mines or not until late 1964, exit happened in a staggered fashion with most exits between 1964 and 1966 (see Figure 5 above). To account for this, I rerun my main analysis in a staggered difference-in-differences event study. In Figure A25 in the Appendix, I show that my results on the quantity spillovers as well as input usage are confirmed by the staggered adoption model.

Note that recent literature (Borusyak et al. 2024, Callaway & Sant'Anna 2021, Callaway et al. 2024*b*, De Chaisemartin & d'Haultfoeuille 2020, Sun & Abraham 2021) has shown that event study results (with continuous exposure) can yield distorted estimates of the treatment effect. However, the relatively high share of never-treated units in my analysis reduces this concern (Borusyak et al. 2024).

Further, Callaway et al. (2024*a*) show that the difference-in-difference model with continuous exposure only identifies a causal effect under a more demanding parallel trends-type assumption. Therefore, I repeat my main analysis in a standard binary difference-in-differences model where I compare mines with strictly positive exposure ($[RV\ Exposure_j] > 0$) to mines with zero exposure (see Figure A26 in the Appendix). Results are qualitatively identical.

Non-Linearity in Treatment Effects. My regression design implicitly assumes that the marginal effect of an increase in the treatment exposure is constant independent of the level of the treatment. To ensure that this does not blur the estimated results, I (i) estimate separate treatment effects for mines with below/above median exposure among the treated mines and (ii) test for quadratic relationships between treatment and outcomes in the Appendix (see Table A6). Both tests indicate that the spillovers are especially driven by highly treated mines.

Exit, Sample Composition, and Selection into Treatment. To capture the whole industry, my analysis included all mines, which were not closed through the policy, in the regressions. However, some mines have been closed before or after the policy and two mines opened in the 1960s, so that the composition of the control and treatment groups varies over time. To ensure that this selection process does not affect my estimation results, I rerun my main analyses in the Appendix for a balanced panel of mines that operated throughout the whole sample period (see Figure A27). I further reproduce my main analysis for a subsample of only multi-mine firms. This ensures that selection into treatment, which is only possible for multi-mine firms as another mine of the same firms needs to be shut down, is not driving the results (see Figure A28).

Identification, Inference, and Weighting by Size. Up to now, I identified spillovers by comparing mines of firms having different treatment exposures within coal districts ($N = 3$) using coal-district fixed effects. In Table A9 in the Appendix, I show that my results are not sensitive to comparing all mines (only year fixed effects) or within more refined coal areas ($N = 7$) which split the large *Ruhr* district into subregions (coal region-year fixed effects). That the results are unaffected by the regional identification cell is further support for the absence of spatial spillovers. With respect to inference, my results are unaffected by using standard errors clustered at the mine level, at the pre-treatment owner level, or using spatial standard errors (Conley 1999) instead. Lastly, I rerun my main estimations of the within-firm analysis for regressions weighted by size, i.e., output in the pre-policy year 1962. This is motivated by the higher relevance of changes in larger mines. Table A10 in the Appendix shows that the treatment effects are slightly larger (however, not always statistically significantly larger) in the weighted regressions. This is also in line with the reallocation towards larger mines.

8 Discussion and Conclusion

In this section, I assess the performance of the closure subsidy relative to other alternative policies and discuss the implications of the paper. Different industrial policies can vary substantially in their economic effects.

Net Employment Effects. Beyond productivity, a policymaker might also care about welfare effects such as those on the labour market which I only marginally considered up to now. At first glance, there is a trade-off between the productivity-oriented policy (i.e., fewer input usage and mine closures of unproductive mines) and employment in the short run. However, this might not be the case in the long run as productivity gains can lead to mines surviving for a longer time and jobs being saved. To incorporate this, I conduct a back-of-the-envelope calculation of net employment effects due to the policy.

The policy led to the closures of mines which employed 87,000 workers right before the policy in 1961. My spillover analysis suggests that actually only 33% of these jobs got lost (i.e., 29,000 jobs).[16] The rest is recovered in the remaining mines. This also already accounts for job loss through the change from labour- to capital-intensive production due to technology adoption.

Further, the spillovers led to productivity gains, so that remaining mines on average survived for six more years. Given that treated mines on average survive 26 years post-policy and make up about 50% of the industry production at the end of my panel in 1971, long-run job savings are substantial. Treated mines employed between 85,000 and 126,000 employees per annum throughout the post-policy years 1963-1971. Smoothing, e.g., 85,000 saved jobs in six years over 26 years, translates to a conservative estimate of 20,000 jobs per annum. This almost fully compensates the job loss due to the policy (29,000 jobs).

[16]Note that this estimate is based on the partial equilibrium assumption that firms that are treated with zero exposure did not reduce their output in response to the policy (e.g., due to lower productivity relative to treated mines). However, my spatial spillover analysis supports this assumption.

Note that job loss due to the decline of the industry would have occurred anyway in closed mines. For example, mines of the upfront part of the policy, *Vorausaktion*, closed without knowing of the premium and earned it ex-post. Thus, the almost full compensation is a lower bound, conservative estimate for the net job gains from the policy. Hence, the policy was not detrimental to employment in the aggregate. However, there are important distributional implications over time with early mass layoffs and late savings.

To also account for across-industry employment spillovers, I provide Figure A5. There are no significant spillovers to other industries in the studied time period.

Closure Subsidy vs. Wage Subsidy. As an alternative to a closure subsidy, the government could sustain jobs by directly subsidizing wages.[17] Instead of downsizing the industry, the government could try to sustain the industry. I calculate back-of-the-envelope costs of a non-discriminating wage subsidy for all mines and a discriminating version for those mines with high exit probabilities only.

Our extensive margin IV regression from Table 1 shows that a one standard deviation increase in labour productivity (mean (sd): 305 (52) tonnes per worker per annum) causes a decrease of 37 p.p. in the probability of exit. Non-discriminatorily subsidizing every sixth shift then implies an effective increase in labour productivity by one standard deviation. In the best scenario, this could lead to not a single mine exiting the market at the time of the policy (31% of mines exited through the policy). Given the fiscal closure premium budget of 350 mio. DM, an average wage of 25.11 DM per shift in 1961 and about 98 million shifts in 1961, this however would take more than the overall premium budget from the closure policy for wage subsidies of just one year. Similarly, subsidizing wages at the employment level as of right after the closure policy given the policy-induced market exit would have been too costly.

In a world where the policymaker knows who will exit, it could target subsidies to those mines. Paying every sixth shift for only those mines that exit through the *RV* would allow the policymaker to pay a subsidy for about three years.

Hence, pure wage subsidies - even if they are targeted - cannot persistently save jobs in my setting.

[17] This is, for example, currently proposed as policy for the declining lignite industry in East Germany (German Federal Ministry for Economic Affairs and Climate Action 2019).

Buy Excess Coal or Subsidize Coal Prices? The policymaker could also increase its own coal demand to save the industry. However, this is too costly. Just the excess, not-sold coal that was stored on pithead stocks between 1964 and 1966 made up 13.6 million tonnes. At an average price of around 80 DM/tonne in these years, purchasing the excess coal for just three years would have cost three times the policy budget. Further, this did not even consider that excess coal production would likely have been higher absent the exit policy.

Similarly, an alternative policy could have been to subsidize the price. In fact, this policy was also debated in the parliament (Bundestag 1965). Assuming the most favorable condition, i.e., full pass-through of price subsidies to consumers, the excess demand of 13.6 million tonnes would require a 2% price cut (following my demand elasticity estimates in Table A1). A 2% price subsidy throughout the first three policy years would, however, cost 670 million DM, i.e., almost twice the government payments for the closure transfers.[18] In fact, Storchmann (2005) shows that policy interventions in the industry after 1970 (mostly price subsidies) were much more costly than the closing subsidy. Again, the volume of excess coal would likely have been higher without the policy.

Economies of Scales and Mergers? Given that large mines usually are more productive, mergers could increase productivity, too, but might be less costly for the policymaker. Throughout my sample, more than twenty mine mergers took place. Since mergers in this industry require that mines are geographically located next to each other, these mine mergers mainly took place within firm among mines of similar productivity level.[19] In Table A11 in the Appendix, I show that they barely affect mine-level outcomes. I only find evidence for a reduction in employment but no effect on productivity, output, capital stock, and survival. Hence, this type of merger would not improve mines' productivity and also lead to employment drops.

Entry? The industry could also gain productivity by opening new mines that dig in very profitable coal fields. The high fixed costs of setting up a mine (several years of preparation) could be financed by the government if firms themselves do not want to enter. However, mines were already quarrying coal in the most northern part of the Ruhr area, where coal layers were the thickest

[18]In fact, the German government subsidized coke coal sales in the 1970s and paid almost 1 billion DM for it.

[19]Also, across-firm acquisitions were hardly possible given the break-up of the industry after World War II (Allied Higher Commission 2019).

and most yielding in Germany. Hence, productivity improvements by opening new coal fields with better geological preconditions would not have been possible.

Policy Improvements. For the future implementation of similar policies in other settings, it is crucial to understand which policy details could have been improved. First, one result of the *RV* is increasing productivity dispersion among surviving mines, i.e., weaker mines remain in the industry, too. The policy could have targeted the exit of such inefficient mines by, for example, introducing heterogeneity in the subsidy by mine or firm size - as size highly correlates with productivity. Further, the policy could have steered the extent of exit by changing the average subsidy size. Lastly, the policy was half financed by competitors paying the exit subsidy. However, quantity spillovers to competitors were limited as I showed above. This raises the question whether the policy should have had a smaller premium participation by competitors. Competitors only profited from the industry-level reduction in overcapacities smoothed across firms through the retail organisations.

Further, I showed that the policy triggered reallocation towards already large and productive mines and the productivity gains centered in these entities. Thus, large, productive mines formed endogenously. A more precise focus on not incentivizing the exit of mines of this type could have been a more targeted policy.

Conclusion. In this paper, I analyse how industrial policy steers exit at the example of an economization scheme in the German coal mining industry. I find that the policy let the 'losers' go and endogenously raised the performance and market share of 'winners' in the industry. The policy fostered technology adoption and productivity gains along various margins: exit of inefficient mines, within-mine productivity gains and reallocation towards large, productive mines. The policy's costs are compensated by marginal costs savings in the industry. More productive mines survive longer prolonging the industry's lifespan and saving jobs in the long run.

This evidence motivates the consideration of exit subsidies as one way to persistently improve an industry's productivity. In contrast to common price or wage subsidies, which often are meant to especially help struggling firms in an industry to keep them alive, this type of policy instead promotes and selects productive firms. My findings are relevant to many industries that are currently in decline such as steel production, non-renewable energy production, or car manufacturing, where optimal mechanisms for capacity reduction are a common debate. For example, in Germany, coal power plants are paid for market exit given the country's goal to a green transmission. In some of these industries, policy-driven productivity gains might be sufficient to keep them alive (for longer), in contrast to the coal industry at hand.

My results, further, are of interest for non-declining industries with temporary overcapacities such as milk, fishing, wine, or vegetable production where incentives for market exit are common policy tools (e.g., Commission of European Union 1988, Council of European Union 2006, Raggi et al. 2015, Commission of European Union 2016). Lastly, my findings have insights for industries in which the policymaker might want to decrease overall production (e.g., phase-out of non-renewable energy production) with increasing productivity and efficiency of the remaining firms at the same time.

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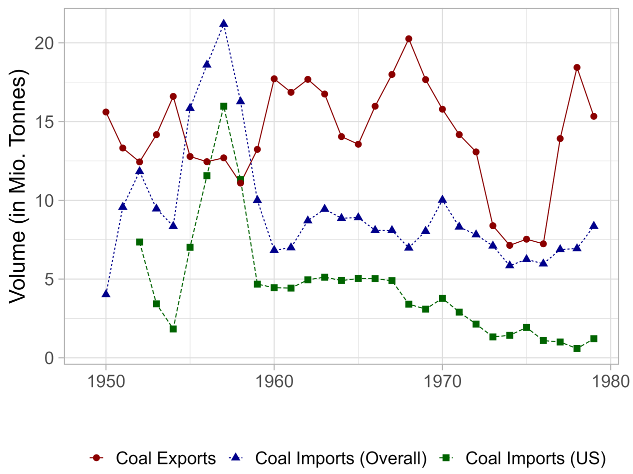
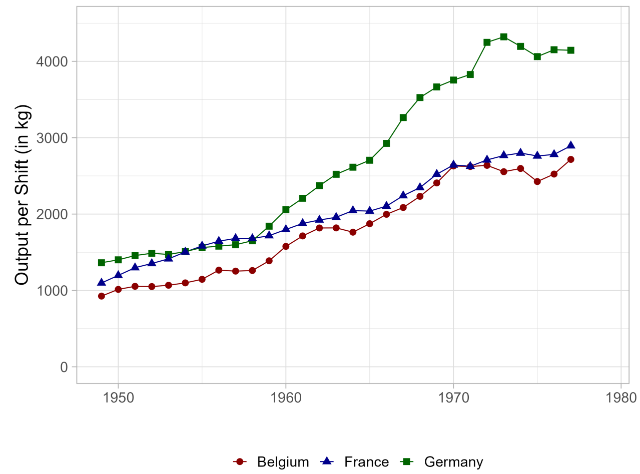
A Additional Figures

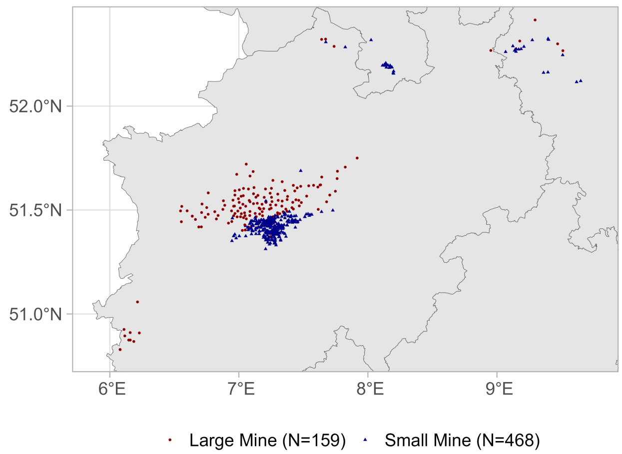


(a) Import/Export Volume

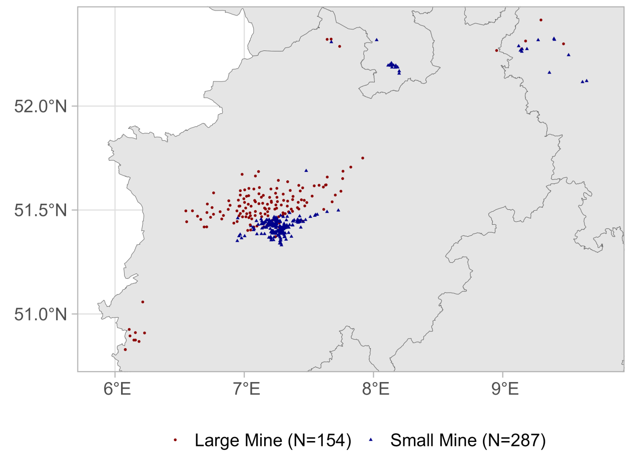


(b) Labour Productivity Across Countries

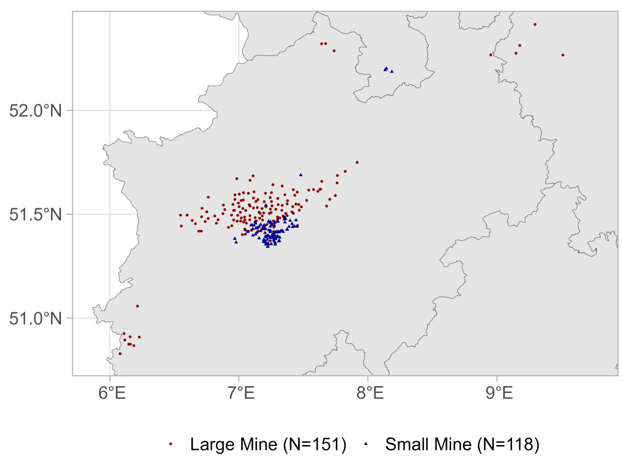
Figure A1: Relevance of Cross-National Coal Trade



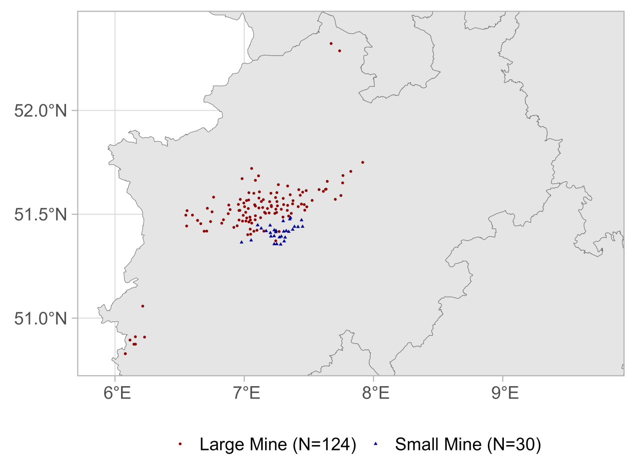
(a) All Mines



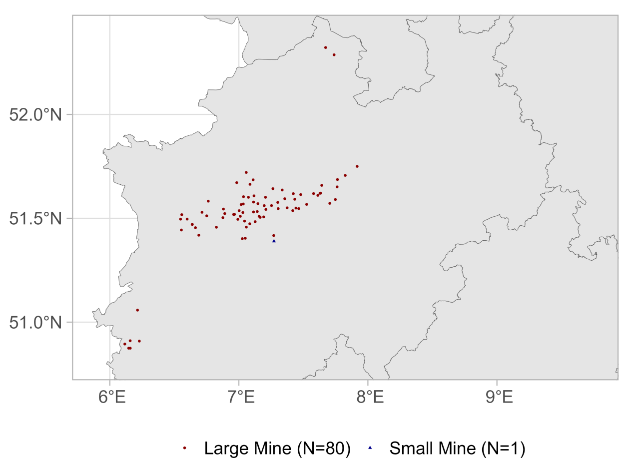
(b) 1951



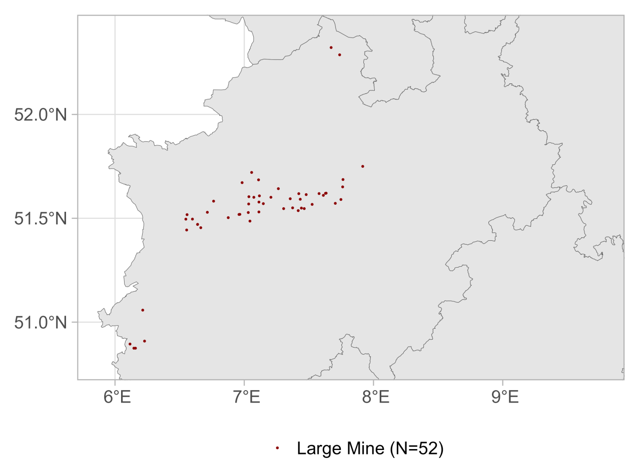
(c) 1958



(d) 1965



(e) 1972



(f) 1979

Figure A2: Mines over Time

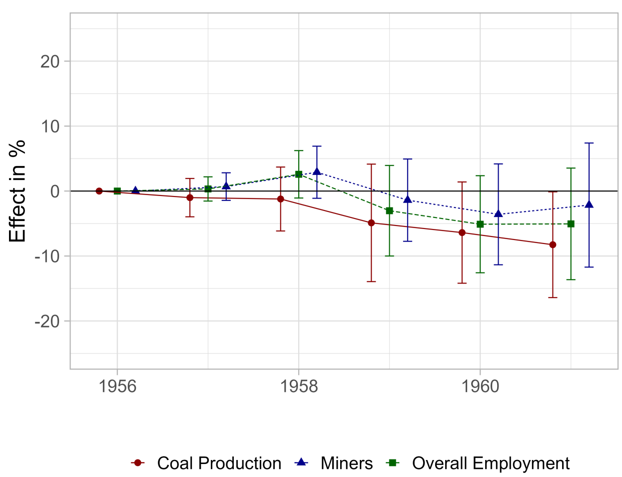
Note: These plots show the location of active mines by year. Mines are classified into large and small mines. Large mines include all mines for which detailed production data is available. Small mines are all other mines. All mines included which operated at least for one year after 1951. For merged mines, I count the joined mines separately in their original independence.

Figure A3: Effect of Mine Closures on Municipality-Level Population

Note: This plot documents the effect of a mine closures on the municipality-level population and workers. The sample is restricted to municipalities in the state of Northrhine-Westphalia, where all coal mines are located (except for few in Lower Saxony). I harmonize municipality boundaries to borders as of today. I weight observations by today's (2022) municipality population. The regression includes municipality fixed effects as well as year fixed effects. For data on working population ('Erwerbstätige'), only census data is used. Standard errors are clustered at the municipality level ($N = 396$) and 90% confidence intervals are reported. The treatment is the number of mines per inhabitant in the year of the mine closure. Hence, the regression has the format:

$$Y_{mt} = \alpha_m + \gamma_t + \sum_{\tau=-6,\tau\neq-1}^{8} \beta_\tau [\frac{\#Mines\ Closed_{m,t-\tau}}{Population_{m,t-\tau}}]_{m,t-\tau} + \epsilon_{mt} \quad (11)$$

where m and t give an index for municipality and year. Municipality and year fixed effects are given by α_m and γ_t. Endpoints are binned. The index of the leads and lags used in the event study is τ. Mine closures are closures of those mines for which productivity data is available, i.e., large mines. The coefficients β_τ of the regressions are multiplied with the median value of $med\{\frac{\#Mines\ Closed_{m,t}}{Population_{m,t}} | \frac{\#Mines\ Closed_{m,t}}{Population_{m,t}} > 0\}$, so that the elasticities in the event study can be interpreted as the effect of one additional mine closure.

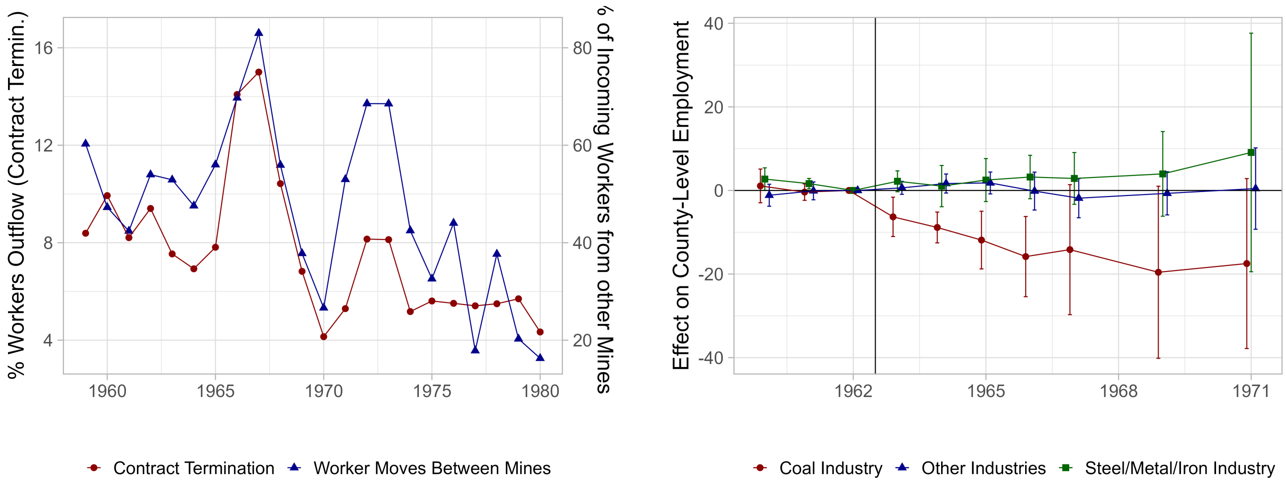


(a) Output/Employment

(b) Productivity

Figure A4: Anticipatory Effects

Note: These plots document how mines, that were closed through this policy, developed in the years prior to the policy (until 1961). I run simple regressions of logged output, employment and standardized productivity measures on mine and district-year fixed effects as well as an dummy for policy-uptaking mines interacted with year fixed effects. No observations of mines in the year of closure are included. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.



(a) Worker Turnover

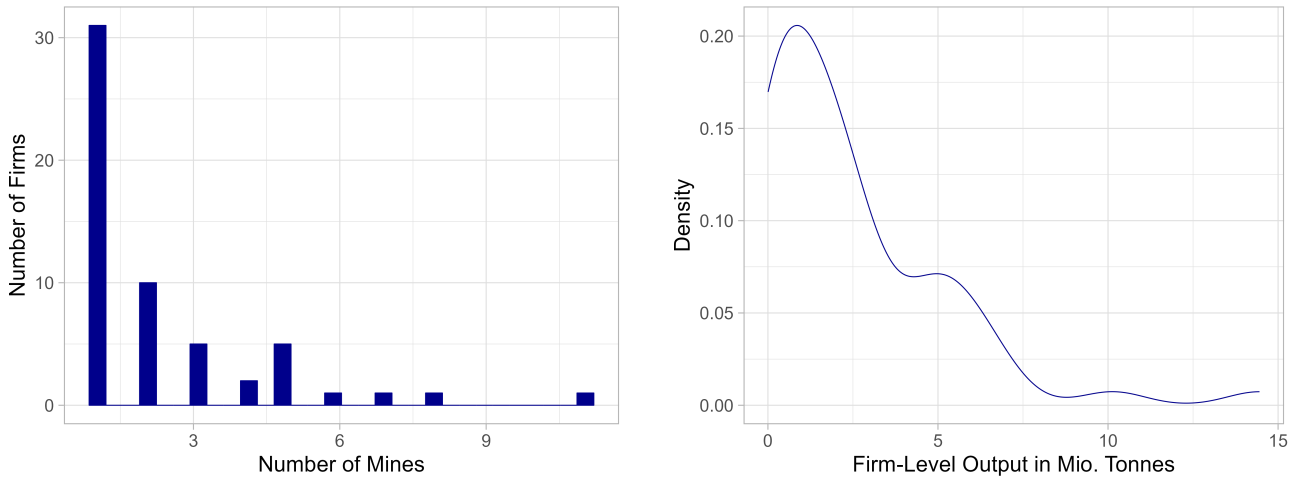
(b) Effect of RV on County-Level Employment

Figure A5: Worker Turnover

Note: The left plot documents two time series: First, the share of workers whose contracts have been terminated (either dismissed or voluntary leave) among all workers per year. Second, the share of workers among all new incoming workers who have been working at a mine before. The right plot documents county-level estimation results of a difference-in-differences estimations of the format:

$$Y_{ct} = \alpha_c + \gamma_{rt} + \sum_{t=1960,\neq 1962}^{1971} \beta_t [\frac{\#Mines\ Closed\ RV_c}{Population_{c,1962}}]_c \times 1[Year = t]_t + \epsilon_{ct} \tag{12}$$

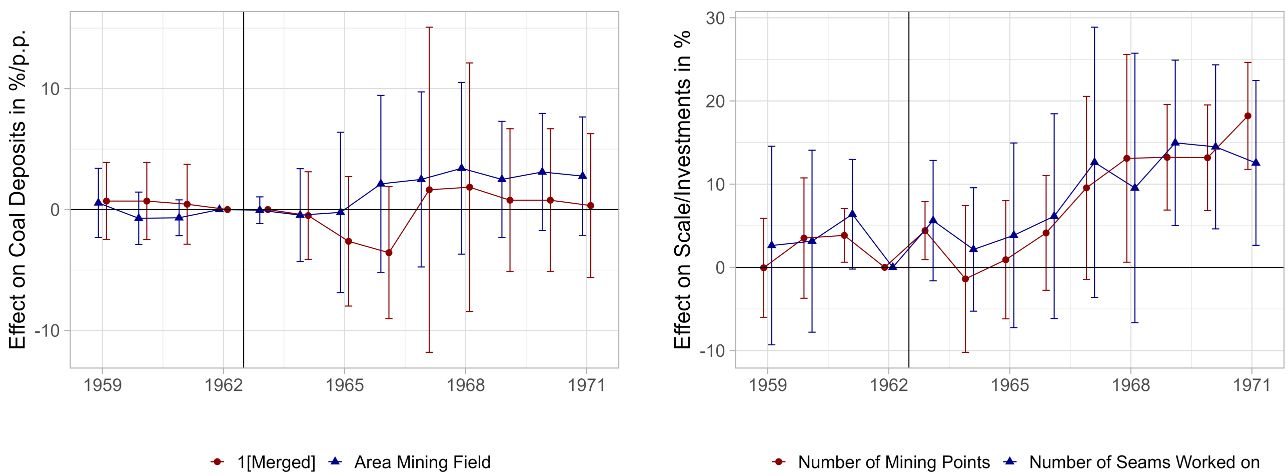
where c and t give an index for county and year. Municipality and Regierungsbezirk-year fixed effects are given by α_c and γ_{rt}. The coefficients β_t of the regressions are multiplied with the median value of $med\{\frac{\#Mines\ Closed\ RV_c}{Population_{c,1962}} | \frac{\#Mines\ Closed\ RV_c}{Population_{c,1962}} > 0\}$, so that the elasticities in the event study can be interpreted as the effect of one additional mine closure. Standard errors are clustered at the county level (counties as of 1971) and 90% confidence bands are reported.



(a) Number of Mines per Firm (b) Output per Firm

Figure A6: Market Structure

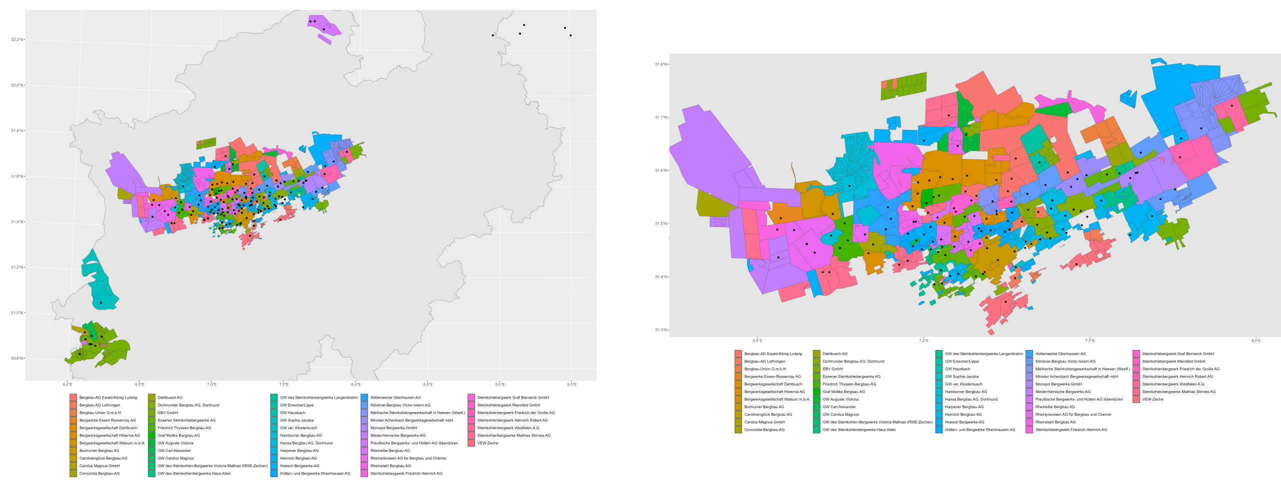
Note: These plots document the distribution of firm size in the industry in the pre-policy year 1962 (small mines, 'Kleinzechen' not included).



(a) Tests of Mine Expansion (b) Within-Mine Capacity Changes

Figure A7: Effect on Capacity Proxies

Note: Based on equation (9). Coefficients multiplied with mean [$RV\ Exposure_j$] for strictly positively treated mines to give an effect for mean exposure for treated mines. This plot documents the effect of the policy uptake on the coal field size and the number of seams of the remaining mines of the same firm. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported.

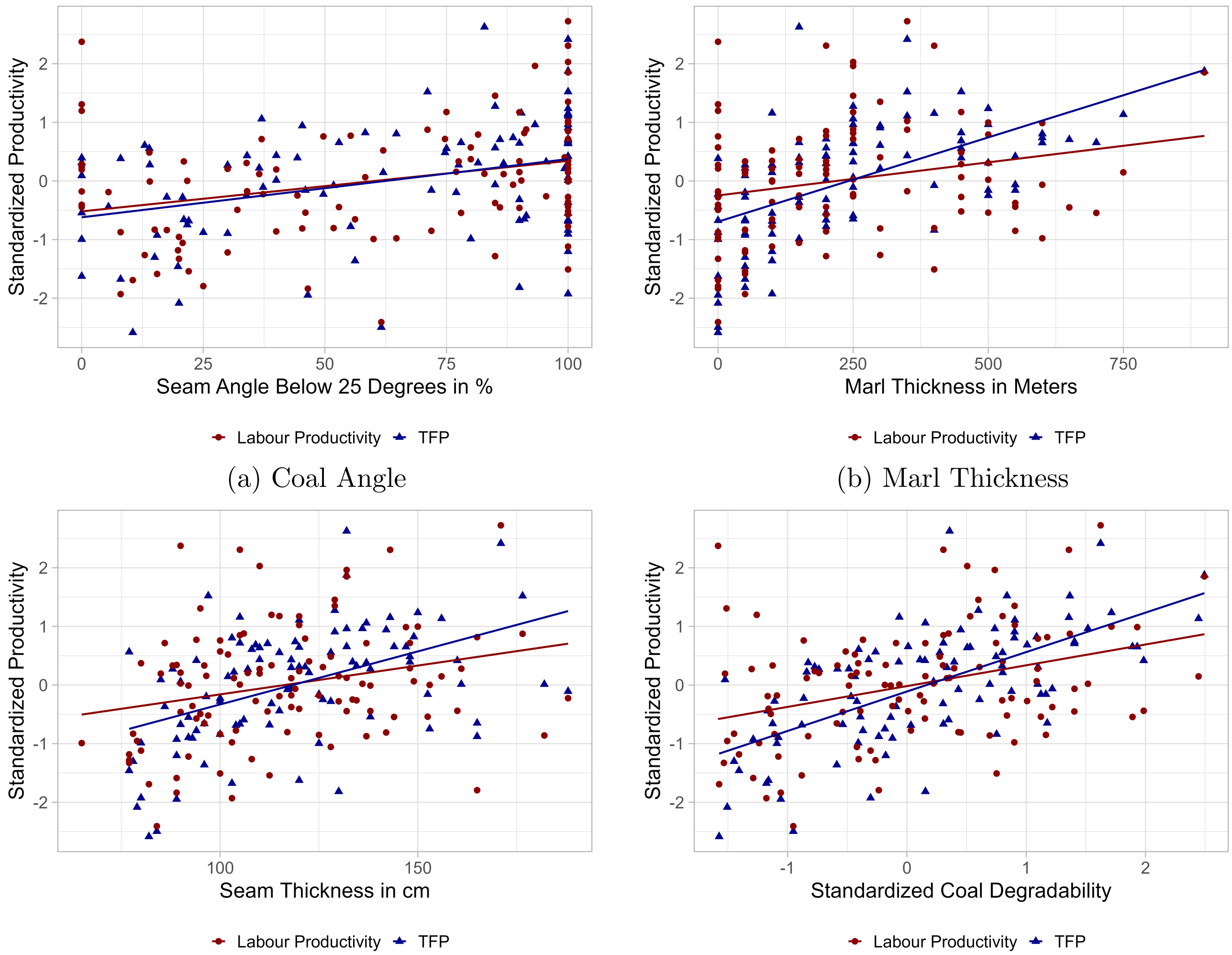


(a) Entire Sample

(b) Ruhr Area Only

Figure A8: Coal Field Ownership in 1962

Note: These plots document the 'Berechtsame' (i.e., coal field ownership) by firms before the policy in 1962. The administrative borders of Northrhine-Westphalia are included.



(c) Seam Thickness (d) Coal Degradability (PCA)

Figure A9: Correlation of IVs and Productivity

Note: These plots give the correlation of the IVs with productivity measures separately and jointly (from predicted values of a principal component analysis). Labour productivity is calculated as the average across the policy-premium relevant years 1959-1961.

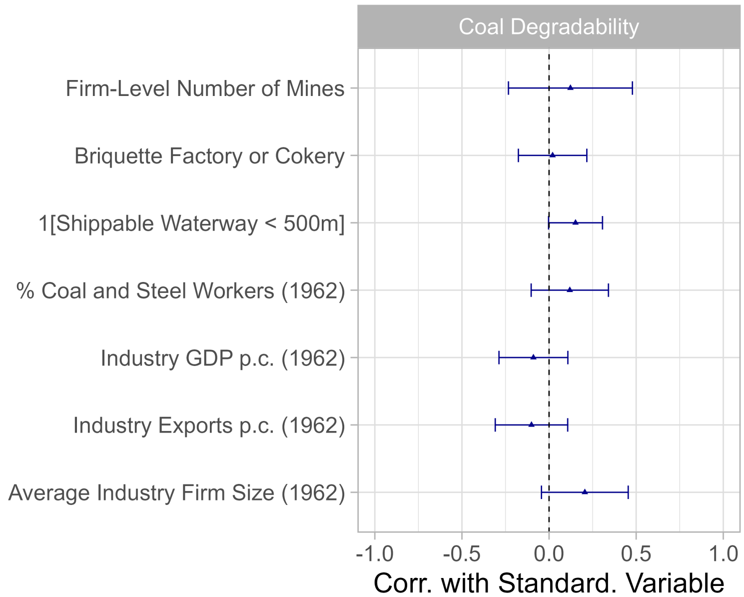


Figure A10: Correlation of IV and Mine-Level or Regional Characteristics

Note: This plot documents the correlation of the mine-level IV with mine-level or regional information for the years 1961 or 1962. Data on industry GDP and exports per capita as well as the share of industrial workers comes from (Statistisches Landesamt Nordrhein-Westfalen 1964). Distance to nearest shippable waterway is calculated based on the shapefile provided by (Wasserstraßen- und Schifffahrtsverwaltung des Bundes 2021).

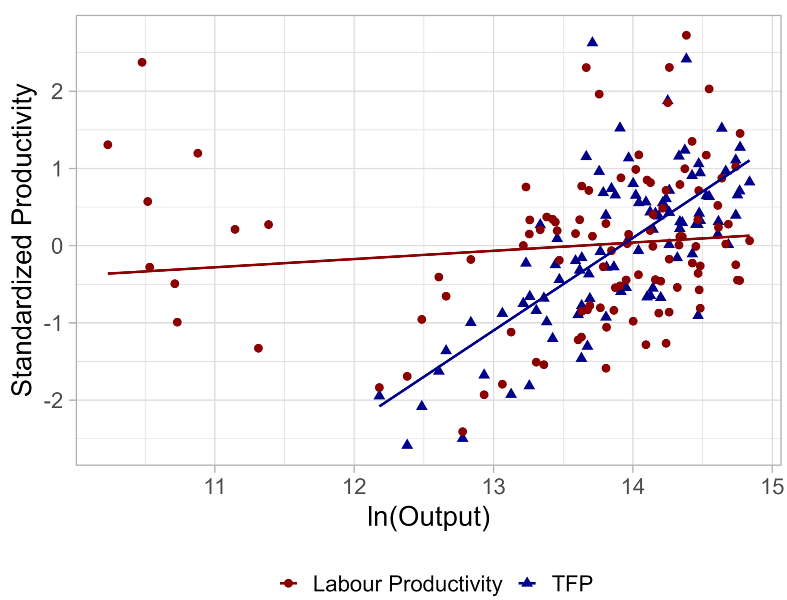


Figure A11: Correlation Firm Output and Mine Labour Productivity

Note: This plot documents th correlation between firm-level output and mine-level labour productivity based on 1961 data for all mines which have been operating for the full year.

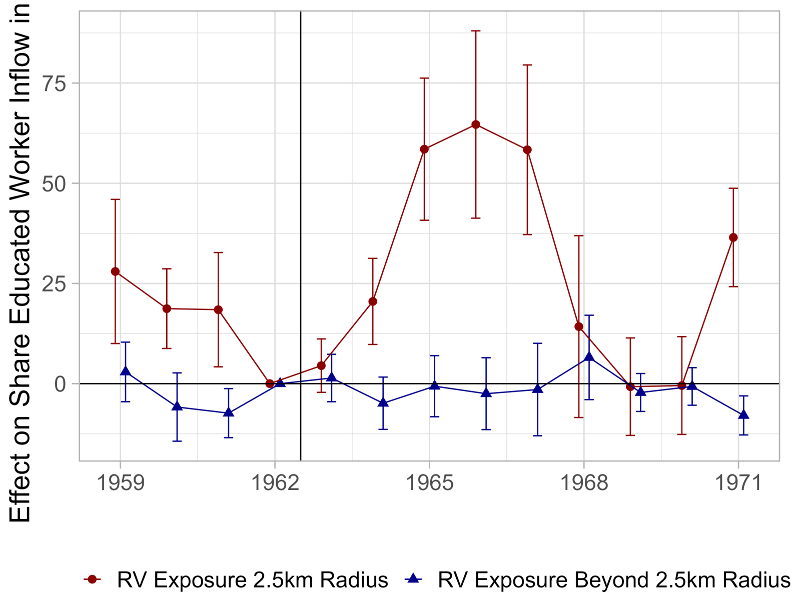
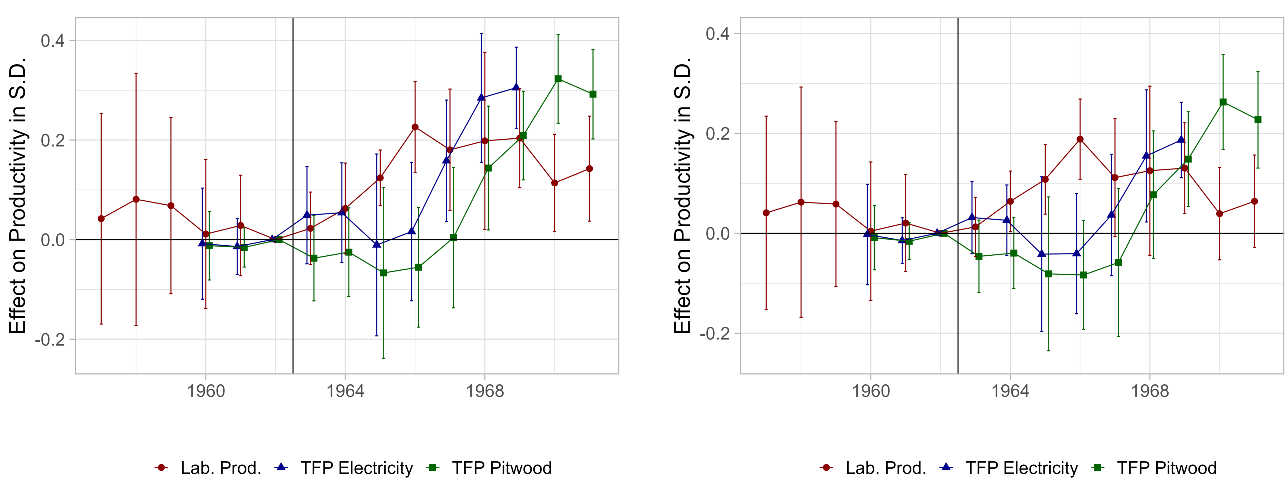


Figure A12: Effect of RV on Share of Educated Workers Among Joining Workers

Note: Based on equation (9) where the treatment exposure is splitted in $[RV\ Exposure_j]$ below and up 2.5km around a mine. Coefficients multiplied with mean $[RV\ Exposure_j]$ within 2.5km for blue line and beyond 2.5km for red line for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported.



(a) Without Output

(b) With Output

Figure A13: Effect on Productivity - With and Without Controlling for Output

Note: Based on equation (9). Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.

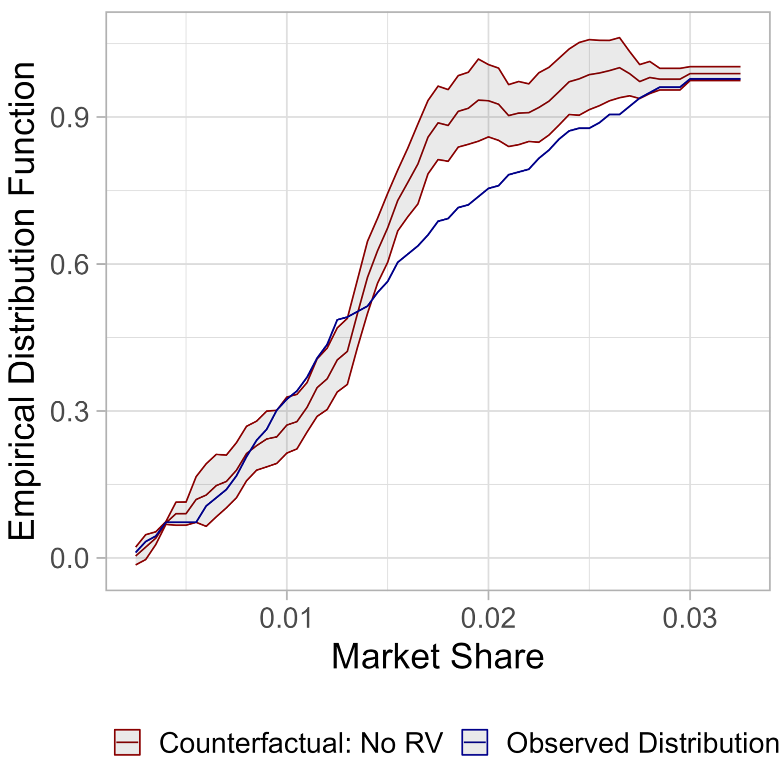


Figure A14: Distributional Effect of RV Policy - Market Shares

Note: Based on distribution regression approach by Chernozhukov et al. (2013). Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported.

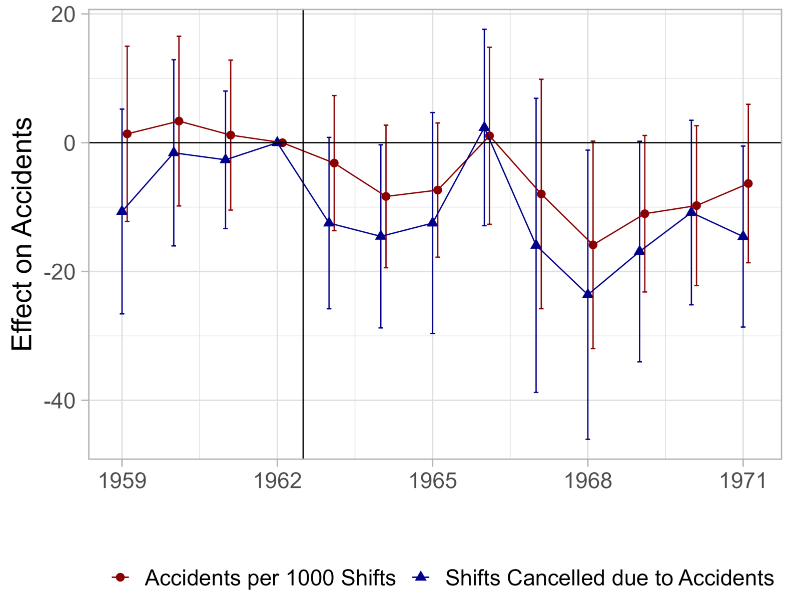


Figure A15: Effect of RV on Accidents

Note: Based on equation (9). Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported.

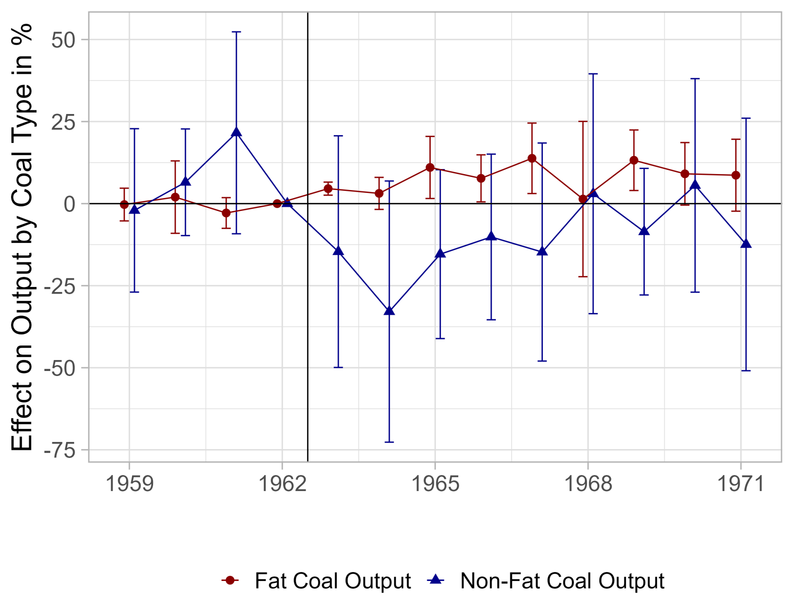
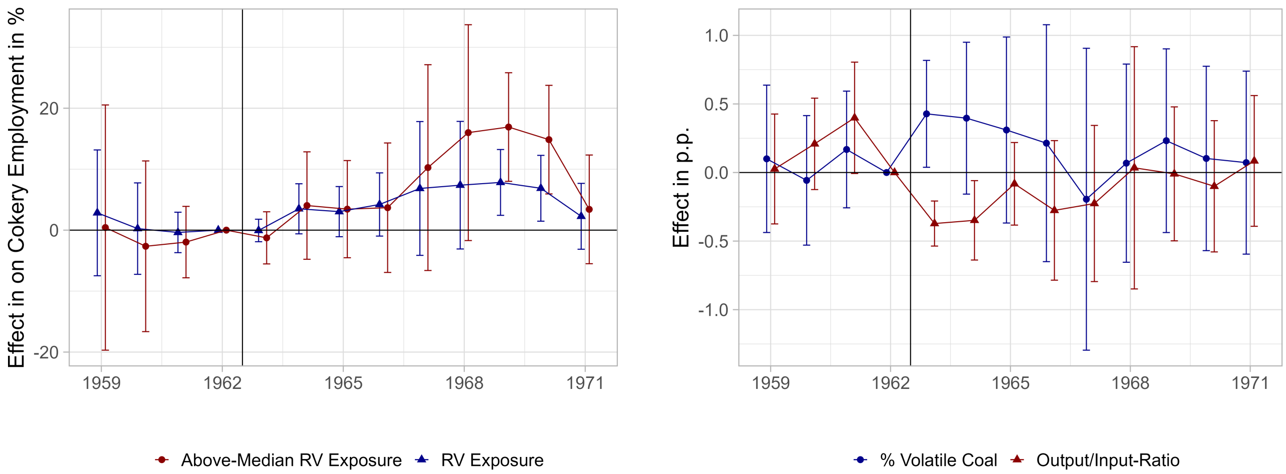


Figure A16: Effect on Share of Production by Coal Types

Note: Based on equation (9). Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence bands are reported.



(a) Cokery Employment

(b) Cokery Efficiency

Figure A17: Effect on Cokery Employment

Note: Based on equation (9). Coefficients multiplied with mean [$RV\ Exposure_j$] for strictly positively treated mines to give an effect for mean exposure for treated mines. Only mines with cokeries over the full sample period (or until mine exit) included (intensive margin). Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported.

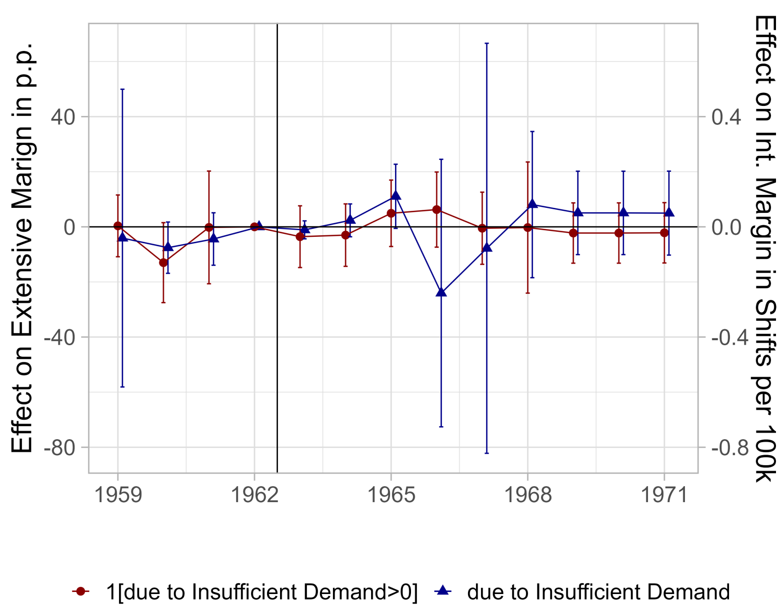


Figure A18: Effect on Cancelled Shifts due to Insufficient Demand

Note: Based on equation (9). Coefficients multiplied with mean [$RV\ Exposure_j$] for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported.

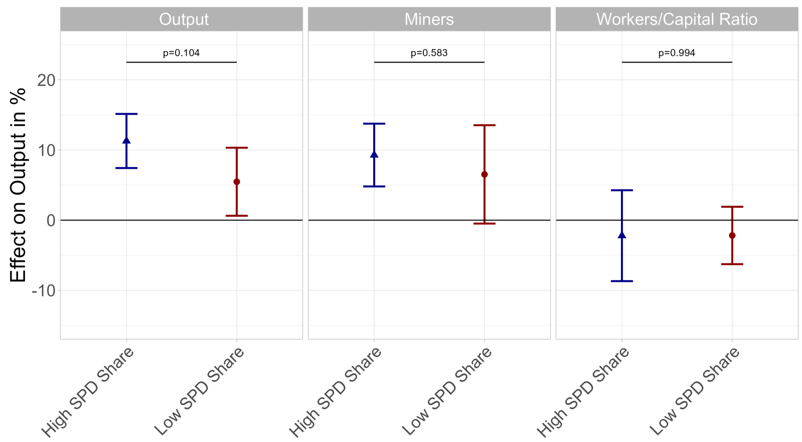


Figure A19: Heterogeneity by Political Attiude

Note: Based on equation (9) with pooled post-dummy with years after the majority of exits took place, i.e., 1965. Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. This plot documents the effect of the policy uptake on output and input usage of the remaining mines of the same firm. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported. Sample is grouped into low and high SPD share at the median, county-level SPD share from the federal election in 1961.

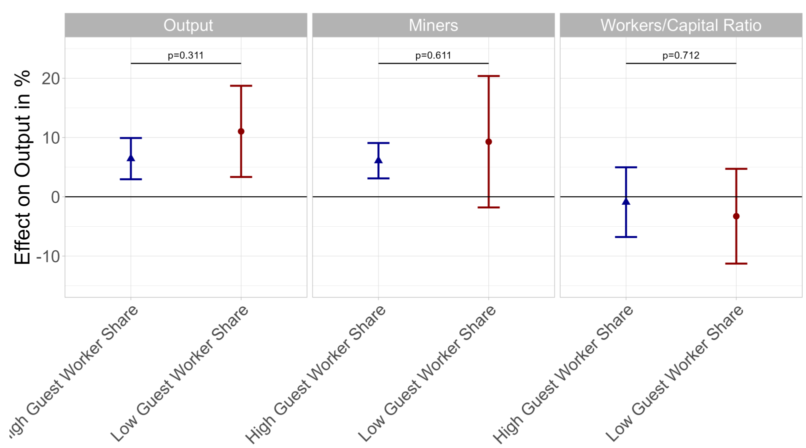


Figure A20: Heterogeneity by *Gastarbeiter* Share in Workforce

Note: Based on equation (9) with pooled post-dummy with years after the majority of exits took place, i.e., 1965. Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. This plot documents the effect of the policy uptake on output and input usage of the remaining mines of the same firm. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported. Sample is grouped into low and high share of freign workers at the median, mine-level share of foreign workers in 1965, the first year the data is available.

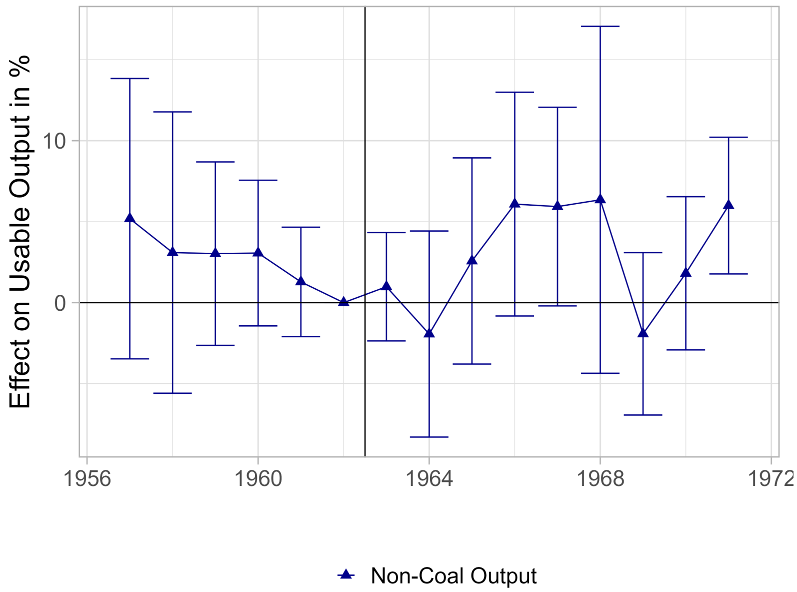
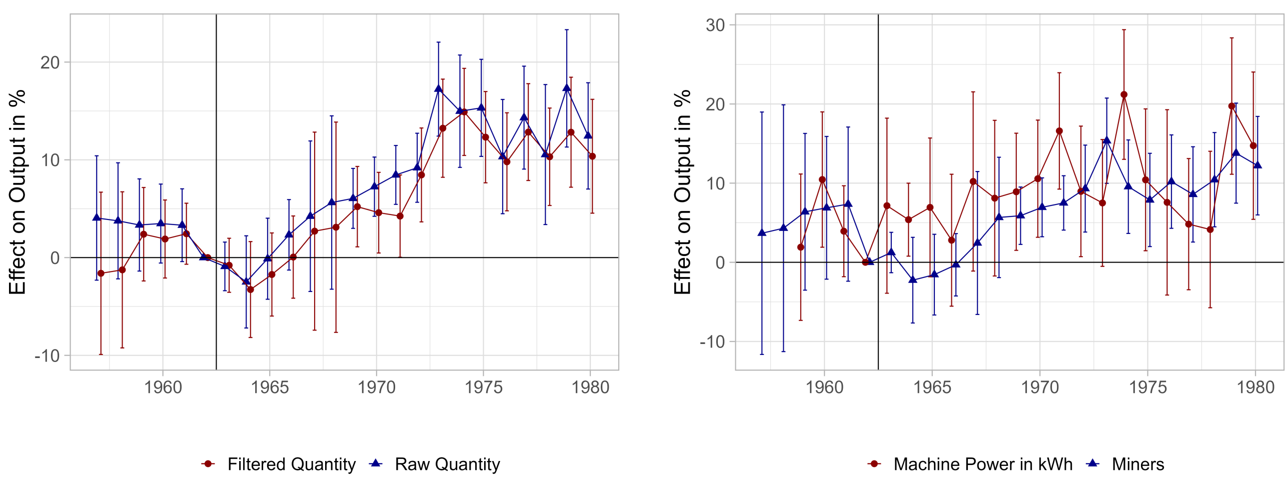


Figure A21: Effect on Non-Coal Output Quarried

Note: Based on equation (9). Coefficients multiplied with mean [$RV\ Exposure_j$] for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported.



(a) Output

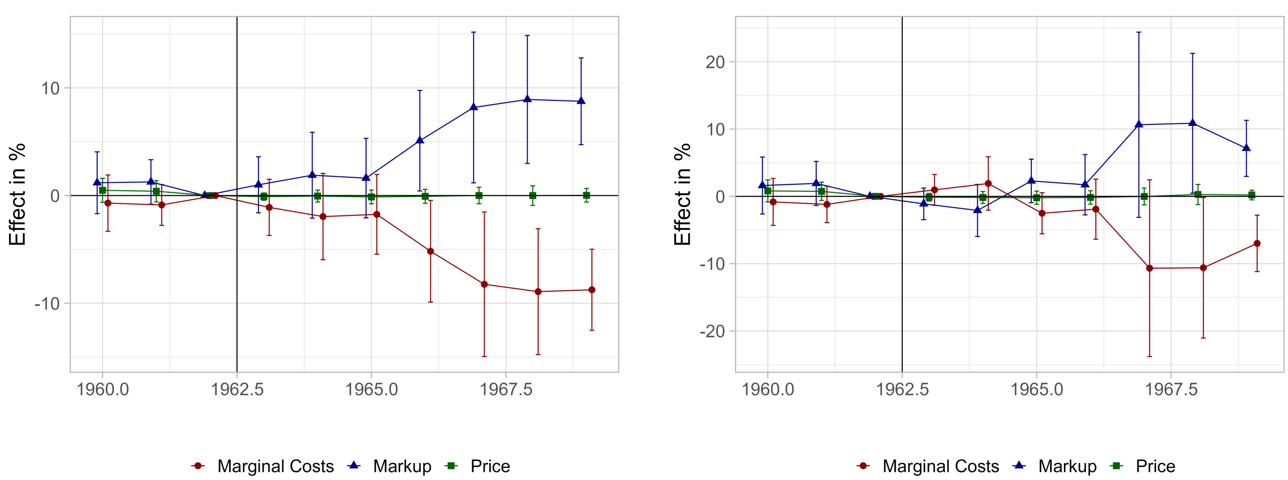
(b) Inputs

Figure A22: Sample until 1980

Note: Based on equation (9). Coefficients multiplied with mean [$RV\ Exposure_j$] for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported. Only mines included which have been in operation throughout the full period 1957 to 1980. Mines are aggregated to their 1980 version in case they merged over time.

Figure A23: Effect on Wages

Note: Based on equation (9). Coefficients multiplied with mean [$RV\ Exposure_j$] for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported.

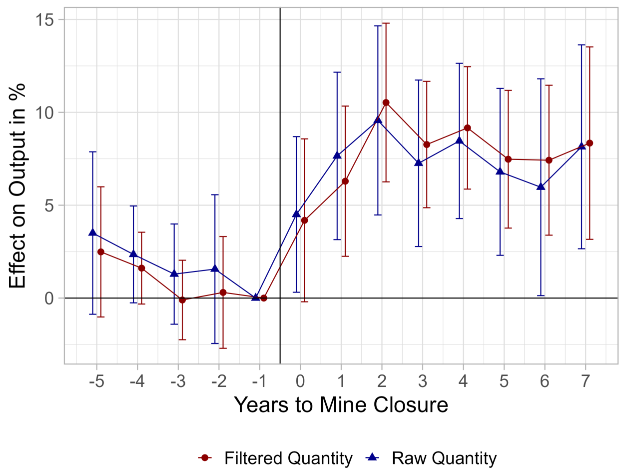


(a) All Mines

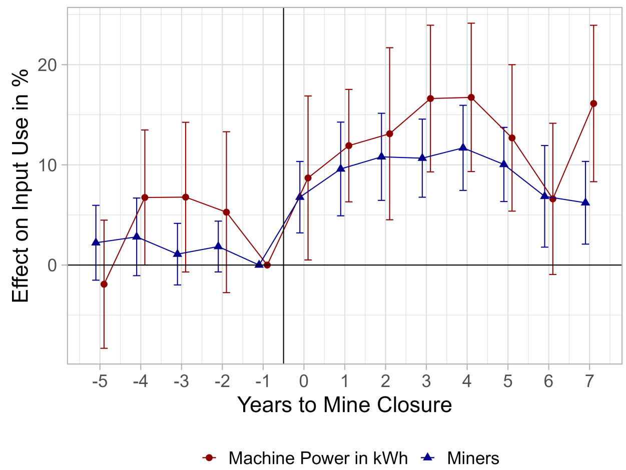
(b) Only Mines with Own Power Plants

Figure A24: Markups based on Electricity as Material with Identical Input Prices

Note: Based on equation (9). Coefficients multiplied with mean [$RV\ Exposure_j$] for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported.



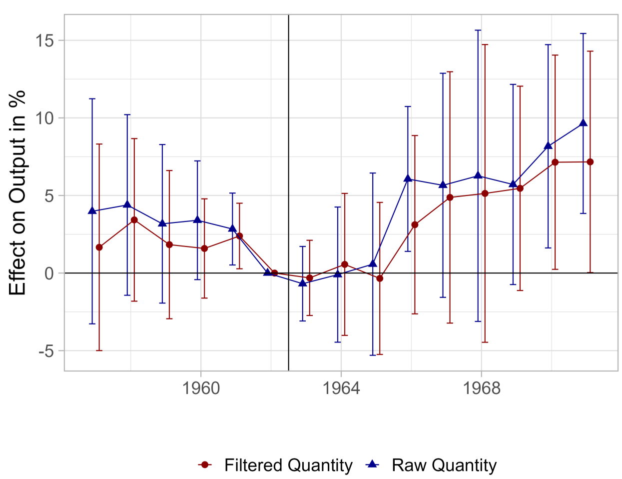
(a) Output



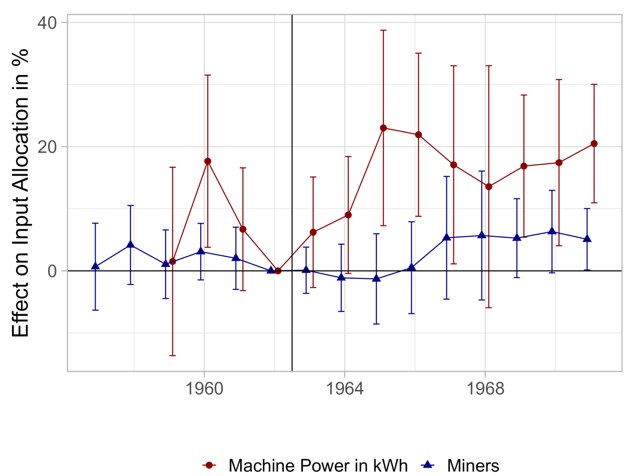
(b) Inputs

Figure A25: Event Study Estimates

Note: This plot documents the effect of the policy uptake on output and input usage of the remaining mines of the same firm. Coefficients multiplied with mean $[RV\ Exposure_j]$ for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported.



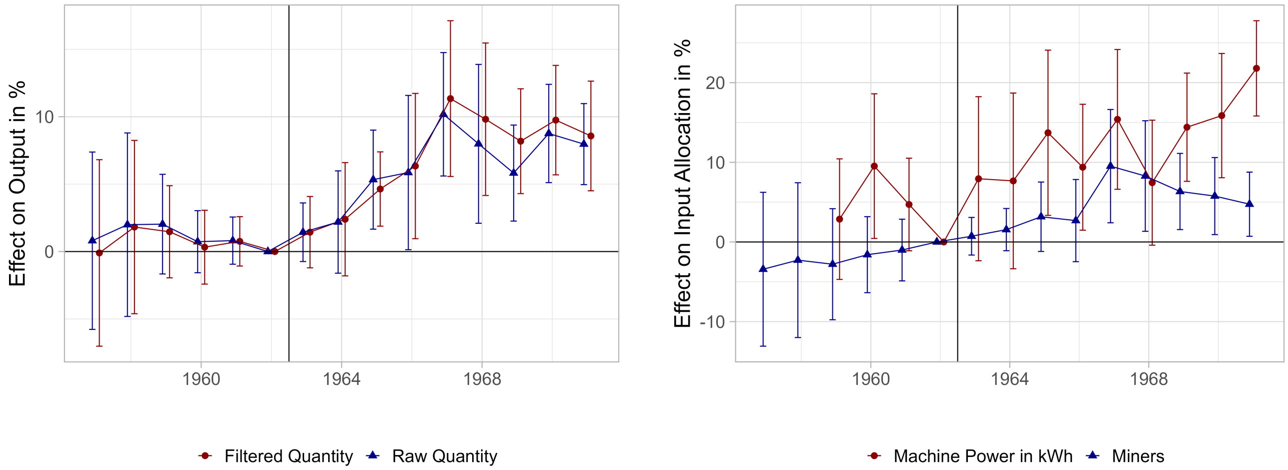
(a) Output



(b) Inputs

Figure A26: Binary Treatment (Extensive Margin)

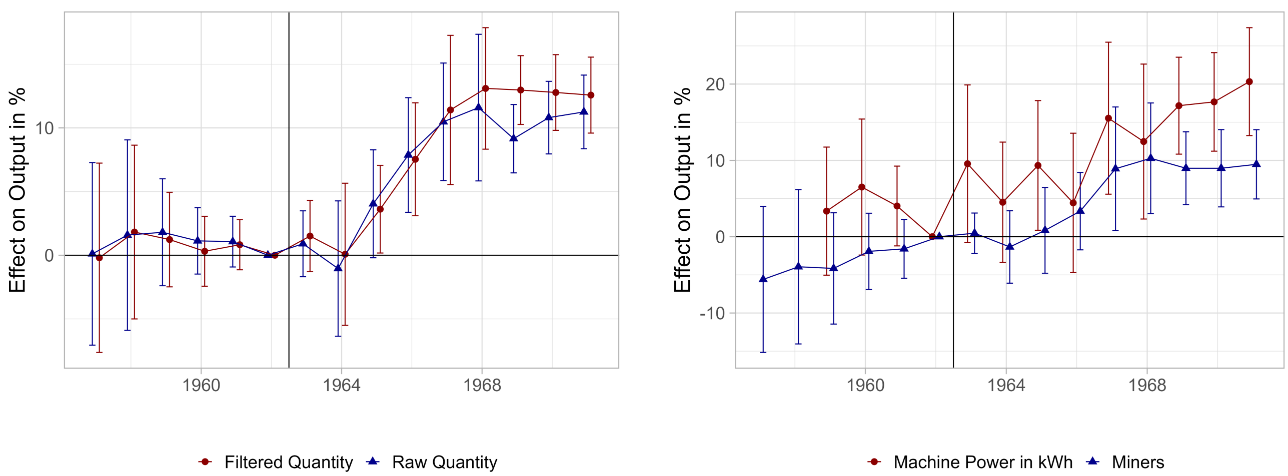
Note: Based on equation (9) with binary exposure. This plot documents the effect of the policy uptake on output and input usage of the remaining mines of the same firm. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported. Treated stations are those with positive $[RV\ Exposure_j]$.



(a) Output (b) Inputs

Figure A27: Balanced Sample

Note: Based on equation (9). This plot documents the effect of the policy uptake on output and input usage of the remaining mines of the same firm. Coefficients multiplied with mean [$RV\ Exposure_j$] for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported. Only mines included which have been in operation throughout the full period 1957 to 1971.



(a) Output (b) Inputs

Figure A28: Sample based on only Multi-Mine Firms

Note: Based on equation (9). This plot documents the effect of the policy uptake on output and input usage of the remaining mines of the same firm. Coefficients multiplied with mean [$RV\ Exposure_j$] for strictly positively treated mines to give an effect for mean exposure for treated mines. Standard errors are clustered at the firm/owner level and 90% confidence intervals are reported. Only mines included which have been owned by a firm that had at least two mines operating in the pre-policy year 1962.

B Additional Tables

Table A1: Elasticities of Demand Over Time

	ln(Coal Output)			
	(1)	(2)	(3)	(4)
Panel A: OLS				
ln(German Coal Price Index)	-1.186^{***}			
	(0.147)			
ln(Oil Price Index)		0.483^{**}		
		(0.114)		
ln(German Coal Price Index)×1[Year≤1958]			-0.114^{***}	
			(0.003)	
ln(German Coal Price Index)×1[Year>1958]			-1.139^{**}	
			(0.262)	
ln(Oil Price Index)×1[Year≤1958]				−0.072
				(0.055)
ln(Oil Price Index)×1[Year>1958]				0.314
				(0.279)
Panel B: Instrumental Variable				
ln(German Coal Price Index)	-1.935^{***}			
	(0.461)			
ln(Oil Price Index)		0.685^{***}		
		(0.141)		
ln(German Coal Price Index)×1[Year≤1958]			-0.665^{***}	
			(0.019)	
ln(German Coal Price Index)×1[Year>1958]			-2.099^{***}	
			(0.232)	
ln(Oil Price Index)×1[Year≤1958]				0.026
				(0.083)
ln(Oil Price Index)×1[Year>1958]				0.849^{***}
				(0.224)
F-Statistic IV	21.19	180.09	21.19	180.09
Observations	17	17	17	17

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Data on years 1955 to 1972. In third row, dummy for years after 1958 is not reported.

Table A2: Descriptive Statistics

Variable	Time Span	N	Mean	SD
RV Uptake				
$1[\text{Closed via } RV]_i$	1956-1971	1,512	0.215	0.411
$1[RV]_i$	1956-1971	1,512	0.380	0.485
Production Data				
Raw Extraction$_{it}$ (in 1000 tonnes)	1957-1971	1,291	1,993.9	1,082.9
Coal Production$_{it}$ (in 1000 tonnes)	1956-1971	1,512	1,252.5	763.7
Workers$_{it}$	1956-1971	1,512	3,549.8	2,178.1
Miners$_{it}$	1956-1971	1,502	2,305.1	1,405.8
Machine Power$_{it}$ (in kWh)	1959-1971	1,060	6,451.1	4,099.2
Electricity Usage$_{it}$ (in kWh)	1959-1969	960	81,821.7	51,368.4
Mine Characteristics				
Conveyor Tunnels$_{it}$	1959-1971	1,069	1.731	0.816
Depth of Mine$_{it}$ (in m)	1959-1971	1,078	913.7	208.9
Coal Layer Thickness$_{it}$ (in m)	1956-1971	1,333	125.4	28.8
% Coal Angle Up to 40 Degrees$_{it}$	1959-1971	1,085	81.22	26.09
Technology Adoption				
Mining Points$_{it}$	1957-1971	1,291	12.94	9.59
Mechanized Mining Points$_{it}$	1959-1971	1,085	5.42	3.66
% Mechanized Production$_{it}$	1959-1971	1,072	65.53	34.00
Others				
Wages$_{it}$ (in DM/Shift)	1957-1969	1,081	31.95	8.37
Wages Miners$_{it}$ (in DM/Shift)	1957-1969	1,081	34.54	9.01
% Shifts Cancelled Due to Insufficient Demand$_{it}$	1957-1969	1,081	0.77	1.60
% Shifts Cancelled Due to Reconstruction$_{it}$	1957-1969	1,081	0.44	0.33
Construction Speed$_{it}$ (cm/Day)	1957-1971	1,284	161.68	75.96
Water Inflow$_{it}$ (in m^3)	1959-1971	1,054	1,925.9	3,031.2

Note: Data is aggregated to mines as of 1971, the end of the panel, to account for mergers throughout the sample period.

Table A3: Production Function Estimation

	Baseline		Robustness	
Production Function:	Leontief		Cobb-Douglas	
Material:	Pit Wood		Electricity	
	(OLS)	(PFA)	(OLS)	(PFA)
$\hat{\beta}_L$	0.794	0.801	0.677	0.696
	(0.030)	(0.181)	(0.054)	(0.105)
$\hat{\beta}_K$	0.175	0.106	0.158	0.103
	(0.047)	(0.052)	(0.025)	(0.041)
$\hat{\beta}_M$			0.149	0.119
			(0.034)	(0.087)
Scale		0.907		0.918
		(0.190)		(0.116)
Median Markup		1.148		1.029
		(0.253)		(0.196)
Observations	922	922	798	798

Note: Standard errors are block-bootstrapped with 100 repetitions for PFA. Standard errors clustered at mine level for OLS.

Table A4: Selection into *RV* Exposure

	1[Owner is *RV* Uptaker]$_i$		[*RV Exposure$_j$*]	
Production Measures				
Standardized TFP	0.065	0.066	0.103*	0.103*
	(0.105)	(0.108)	(0.056)	(0.057)
log(Coal Production)	0.267	0.369	−0.157	−0.122
	(0.293)	(0.360)	(0.118)	(0.140)
log(Miners)	−0.035	−0.196	0.171	0.123
	(0.313)	(0.328)	(0.139)	(0.151)
log(Machine Power)	−0.064	−0.088	−0.114	−0.122
	(0.178)	(0.190)	(0.085)	(0.090)
log(Mining Points)	−0.159	−0.088	0.008	0.026
	(0.193)	(0.193)	(0.069)	(0.070)
% Mechanized Production	−0.001	−0.0003	0.001	0.001
	(0.003)	(0.003)	(0.001)	(0.001)
Mine Characteristics				
Mergel Depth	0.0006*	0.0006*	−0.0001	−0.0001
	(0.0003)	(0.0003)	(0.0001)	(0.0001)
log(Historical Coal Layer Thickness)	0.103	0.198	0.104	0.129
	(0.461)	(0.481)	(0.187)	(0.194)
% Coal Layers up to 25 Degrees	0.002	0.002	0.002	0.002
	(0.003)	(0.003)	(0.001)	(0.001)
log(Year of Mine Foundation)	−1.302	−1.831	−1.817	−1.943
	(4.917)	(4.797)	(1.637)	(1.669)
log(Coal Layer Thickness)	−0.244	−0.263	−0.020	−0.023
	(0.344)	(0.360)	(0.157)	(0.170)
Coal Type				
% Lean Coal	0.003	0.004	−0.002	−0.001
	(0.003)	(0.004)	(0.002)	(0.002)
% Fat Coal	−0.002	−0.001	−0.001	−0.001
	(0.003)	(0.003)	(0.001)	(0.001)
% Anthracite Coal	0.003	0.002	−0.001	−0.001
	(0.002)	(0.003)	(0.001)	(0.001)
% Gas Coal	−0.001	−0.001	−0.001	−0.001
	(0.002)	(0.002)	(0.001)	(0.001)
Firm Characteristics				
ln(Number of Mines)	0.667***	0.659***	0.126***	0.124***
	(0.075)	(0.075)	(0.028)	(0.028)
Coal District FE	No	Yes	No	Yes
Observations		67		

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Omitted category in share of coal production is charcoal. Values as of 1962, the pre-policy year. Standard errors clustered at firm/owner level ($N = 35$). Small mines ('Kleinzechen') included. Coefficient of intercept in model (1) and (3) not reported.

Table A5: Robustness Checks: Extensive Margin

	1[Closure via RV]$_i$					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: OLS						
$\log(\hat{c}_i)$	1.352***	1.365***	1.251***			
	(0.176)	(0.294)	(0.316)			
Standardized TFP$_i$				see baseline results Table 1		
1[High Cancelled Shifts]$_i$			0.456***			
			(0.118)			
1[Closure of Same Coal Type Mine]$_i$			−0.489***			
			(0.099)			
Panel B: Instrumental Variable						
$\log(\hat{c}_i)$	2.175***	2.802***	2.192***			
	(0.443)	(0.725)	(0.539)			
Standardized TFP$_i$				−0.749***	−0.247*	−0.126
				(0.173)	(0.129)	(0.159)
1[High Cancelled Shifts]$_i$			0.456***	0.195	0.370**	0.412**
			(0.108)	(0.200)	(0.159)	(0.160)
1[Closure of Same Coal Type Mine]$_i$			−0.434***	0.108	−0.342**	−0.451***
			(0.142)	(0.196)	(0.153)	(0.162)
F-Statistic First Stage	*22.89*	*18.90*	*16.41*	*38.07*	*10.70*	*8.90*
IV	Pooled IV	Pooled IV	Pooled IV	Coal Angle	Marl Thickness	Seam Thickness
Mining District FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm/Owner FE	No	Yes	Yes	Yes	Yes	Yes
Observations	96	96	96	96	96	96

Note: Significance levels of 10%, 5% and 1% are denoted by *, ** and ***. Marginal costs is averaged over 1960-1961 (no data for 1959). All individual IVs standardized. Standard errors are clustered at the firm/owner level.

Table A6: Non-Linear Treatment Effects

	ln(Output)	ln(Machinery)	ln(Miners)
Panel A: Below/Above Median			
$[Low\ RV\ Exposure_j] \times 1[Year > 1965_t]$	0.094	0.345	0.095
	(0.193)	(0.592)	(0.219)
$[High\ RV\ Exposure_j] \times 1[Year > 1965_t]$	0.595***	0.790**	0.722***
	(0.151)	(0.293)	(0.129)
Panel B: Quadratic Relationship			
$[RV\ Exposure_j] \times 1[Year > 1965_t]$	−0.126	−0.117	−0.315
	(0.260)	(0.390)	(0.260)
$[RV\ Exposure_j]^2 \times 1[Year > 1965_t]$	0.760**	0.839	1.055***
	(0.362)	(0.650)	(0.351)
Mine FE	Yes	Yes	Yes
Coal District - Year FE	Yes	Yes	Yes
Observations	1,012	861	1,012

Note: Based on equation (9) with adapted treatment variable and pooled post-dummy with years after the majority of exits took place, i.e., 1965.* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are clustered at firm/owner level.

Table A7: Production Function: Robustness Checks

	Standardized TFP				**St. LP**	**Standardized TFP**	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Production Function	Leontief	C.-D.	Translog	Leontief	LP	Leontief	Leontief
Material Input	Pit wood	Electric.	Pit wood	Pit wood	-	Pit wood	Pit wood
Sample Period	'59-'71	'59-'69	'59-'71	'59-'80	'59-'80	'59-'71	'59-'71
Other Change						Time-Variant PF	Mechanization
Panel A: Effect after 1965							
$[RV\ Exposure_j] \times 1[Year > 1965_t]$	0.677***	0.695***	0.441*	0.497**	0.486***	0.139	0.353
	(0.248)	(0.193)	(0.248)	(0.227)	(0.124)	(0.090)	(0.237)
Panel B: Effect after 1967							
$[RV\ Exposure_j] \times 1[Year > 1967_t]$	1.062***	1.037***	0.742***	0.238*	0.365***	0.236***	0.413***
	(0.129)	(0.137)	(0.169)	(0.149)	(0.129)	(0.045)	(0.129)
Mine FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coal District - Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	922	798	922	1,064	1,289	922	922

Note: Based on equation (9) with pooled post-dummy with years after the majority of exits took place, i.e., 1965. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are clustered at firm/owner level.

Table A8: Production Function: Robustness Checks Exit

	$1[Closure\ via\ RV]_i$							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Production Function	Cobb-Douglas		Translog		Leontief		Leontief	
Material Input	Electricity		Pit Wood		Pit Wood		Pit Wood	
Other Change					Time-Var. PF		Mechanization	
Panel A: OLS								
Standardized TFP_i	-0.138^{***}	-0.214^{***}	-0.114^{**}	-0.169^{***}	-0.054	-0.105^{**}	-0.082^{*}	-0.081^{**}
	(0.048)	(0.065)	(0.045)	(0.047)	(0.044)	(0.047)	(0.049)	(0.040)
Panel B: IV								
Standardized TFP_i	-0.281^{***}	-0.387^{***}	-0.349^{***}	-0.394^{***}	-0.465^{***}	-0.557^{***}	-0.333^{***}	-0.411^{***}
	(0.063)	(0.116)	(0.081)	(0.100)	(0.131)	(0.154)	(0.078)	(0.147)
F-Statistic First Stage	*41.16*	*24.37*	*33.44*	*27.20*	*15.92*	*13.89*	*29.38*	*10.30*
Owner FE	No	Yes	No	Yes	No	Yes	No	Yes
Coal District FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	96	96	96	96	96	96	96	96

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are clustered at firm/owner level.

Table A9: Identification and Inference

	log(Output) (1)	log(Miners) (2)	log(Machinery) (3)
Panel A: Baseline			
$[RV\ Exposure_j] \times 1[Year > 1965_t]$	0.318^{***}	0.299^{**}	0.376^{***}
(cluster firm)	(0.100)	(0.111)	(0.139)
(cluster firm 1962)	(0.141)	(0.167)	(0.154)
(cluster mine)	(0.120)	(0.137)	(0.149)
(Conley spatial - 12km)	(0.106)	(0.099)	(0.131)
Panel B: Year FE instead of Coal District-Year FE			
$[RV\ Exposure_j] \times 1[Year > 1965_t]$	0.288^{***}	0.290^{**}	0.309^{*}
	(0.107)	(0.109)	(0.166)
Panel C: Coal Region- instead of Coal District-Year FE			
$[RV\ Exposure_j] \times 1[Year > 1965_t]$	0.277^{***}	0.227^{**}	0.285^{**}
	(0.090)	(0.088)	(0.126)
Observations	1,012	1,012	861

Note: Based on equation (9) with pooled post-dummy with years after the majority of exits took place, i.e., 1965. Significance levels of 10%, 5% and 1% are denoted by *, ** and ***.

Table A10: Analysis Weighted by Mine Size

	log(Output) (1)	log(Miners) (2)	log(Machinery) (3)
Panel A: Baseline			
$[RV\ Exposure_j] \times 1[Year > 1965_t]$	0.269***	0.233**	0.324**
	(0.093)	(0.101)	(0.135)
Panel B: Weighted by Output in 1962 (i.e., Mine Size)			
$[RV\ Exposure_j] \times 1[Year > 1965_t]$	0.365***	0.309***	0.373***
	(0.075)	(0.075)	(0.118)
Mine FE	Yes	Yes	Yes
Coal District-Year FE	Yes	Yes	Yes
Observations	970	970	834

Note: Based on equation (9) with pooled post-dummy with years after the majority of exits took place, i.e., 1965. Only observations of mines which operated in the pre-policy year 1962 included (to have a weight). Hence, baseline results slightly change. Significance levels of 10%, 5% and 1% are denoted by *, ** and ***.

Table A11: Merger Effects

	log(Output)	log(Miners)	log(Machinery)	Stand. LP	Standardized TFP Pit Wood	Standardized TFP Electricity	1[Survival]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1[Post-Merger]	−0.065	−0.085**	0.027	0.034	−0.036	−0.069	−0.016
	(0.040)	(0.032)	(0.055)	(0.061)	(0.121)	(0.096)	(0.085)
Observations	1,012	1,012	861	1,012	778	660	4,544

Note: Based on equation (9) with pooled post-dummy with years after the majority of exits took place, i.e., 1965. Significance levels of 10%, 5% and 1% are denoted by *, ** and ***. I control for the RV policy by adding a $[RV\ Exposure_j] \times 1[Year > 1965_t]$ interaction to the regression but omit the output.