Coal Plants, Pollution, and Structural Transformation

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Abstract

We show how access to electricity drives structural transformation in India. Using village-level data from population and economic censuses, we document increases in manufacturing employment and decreases in agricultural employment following the opening of a coal-fired power plant near a village. We also show that these increases are driven by increases in employment in larger firms. Evidence suggests there are increases in both the availability and consistency of electricity. Importantly, we show that areas exposed to pollution from coal plants see decreases in access to electricity and decreases in population and literacy rates relative to less exposed areas, despite an increase in employment concentration in larger firms. These results suggest that access to electricity can be a driver of the structural transformation process, but that the resulting pollution can be an important mediator.

Keywords: structural transformation, agriculture, labor, electricity, pollution, India

JEL Codes: J21, O12, O13, Q53

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1 Introduction

Access to electricity can lead to the establishment of new industries that rely on power and an influx of workers to the areas where the power is generated, leading to urbanization. Yet, many developing countries have consistently experienced power crises due to widespread power shortages and unreliable power supply. Examples include the Brazilian energy crisis in 2001, the 2019 Venezuelan blackouts, and the South African energy crisis in 2020. In South Asia, the India Blackout of 2012 was one of the largest power disruptions in history, affecting hundreds of millions of people. In addition to inconveniencing the daily lives of people in developing countries, these power shortages can also cause crises in the manufacturing sector due to halted or reduced production, which has national economic repercussions, affecting countless jobs and businesses (Fisher-Vanden et al., 2015; Allcott et al., 2016; Cole et al., 2018; Lee et al., 2020).

In contrast to advanced economies, where reliance on coal-fired power plants has diminished, many developing countries still heavily rely on such plants to address their energy shortages. India, in particular, has a rapidly growing population and high demand for electricity, with half of the country's electricity needs met through India's vast coal reserves.[1] While increased access to electricity undoubtedly has positive effects, it is unclear how coal-fired power generation in developing countries affects the economic structure of the region. In particular, given that coal power generation produces severe air pollutants (Mendelsohn, 1980; Covert et al., 2016; Peng et al., 2018; Oberschelp et al., 2019), it is important to understand the impact of air pollution on the economic and industrial structure of neighboring regions.

We investigate whether the establishment of a new coal plant causes structural transformation at the village level in India. First, by combining both population and economic censuses

[1]As of May 31, 2023, coal-fired power plants account for 49.1% of share in the total installed power generation, boasting 205,235 megawatts (MW). Despite the rise of non-fossil fuel sources contributing 43.0% to the total installed capacity, coal remains indispensable in ensuring a stable and consistent power supply, emphasizing its importance in India's energy portfolio. For more details, see https://powermin.gov.in/en/content/power-sector-glance-all-india

from the Socioeconomic High Resolution Rural-Urban Geography Dataset for India (Asher et al., 2021) with with GPS information from the Global Coal Plant Tracker, we study how the establishment of coal plants affects actual electricity supply at the village level. The findings show that villages within 50 kilometers of a coal plant have higher access to electricity. Leveraging monthly data on nighttime lighting in each village, we also show that the establishment of a coal plant has a positive impact on both the amount of electricity a village receives and the reliability of that supply. Moreover, we find that coal plants increase the population of villages and lead to increased literacy rates. This suggests that the power plants lead to higher levels of human capital in the affected areas.

Having established that coal plant construction increases access to electricity, we then turn to structural transformation across sectors. We find that the establishment of a coal plant near a village reduces the share of agricultural employment and the number of actual workers in the sector. Similarly, using firm data excluding agricultural firms, we find that employment in manufacturing increases. More specifically, we see a decrease in the share of home-based manufacturing – a relatively low-paying sector in India (Merfeld, 2020) – and a significant increase in the number of workers in relatively large firms employing 21 or more workers. These results suggest that the introduction of coal-fired power plants leads to a structural shift between sectors, with employment shifting from agriculture to manufacturing and, possibly, from the informal to the formal sector. This provides one piece of evidence that the establishment of a coal plant represents a typical stage of development that marks a shift in the traditional structural transformation phase in which less developed countries experience more sustained economic growth.

Furthermore, our research shows that the gender gap in employment is narrowing in non-agricultural firms. Considering that, in developing countries, women are often trapped in home-based agriculture or informal domestic work without equal access to the labor force, limiting the flow of female labor into manufacturing (Fletcher et al., 2017; Jayachandran, 2021; Merfeld, 2023), our results provide evidence that the establishment of coal plants could contribute to structural changes in the labor market by reducing the gender disparity at the village level, at least in relative terms. In absolute terms, on the other hand, we see larger changes in employment for men than women, though the lower baseline for women means the relative change is much larger.

Next, we test the hypothesis that regions that are relatively more exposed to air pollution from new coal plants may experience different patterns of economic restructuring than other regions. Leveraging daily wind data from the remote sensing system's CCMP wind vector analysis product (Mears et al., 2022), we measure changes in local exposure to air pollution from coal-fired power generation. Our findings indicate that areas with greater exposure to air pollution have relatively lower access to electricity, lower population counts, and lower literacy rates, suggesting that households in polluted areas tend to migrate to other areas and thereby experience less benefit from coal-fired power generation.

More importantly, we find that villages with greater exposure to air pollution from coal-fired power generation experience a larger exodus of agricultural sector workers, a decrease in the proportion of households engaged in small-scale manufacturing, and an increase in the proportion of casual and day laborers who are classified as vulnerable. Given the damage that air pollution does to public health and the costs to the agricultural sector from ecosystem disruption (Agrawal, 2005), our finding suggests that there has been an outflow of full-time agricultural workers from areas more affected by pollution from coal fuels. On the other hand, the share of employment in manufacturing firms increased in regions more exposed to pollution. This increase is much more pronounced in large firms than in small firms. Taken together, these two findings suggest that the influx of workers into manufacturing, which is dominated by large firms, is more pronounced in regions more exposed to air pollution from coal-fired power generation.

Our findings reveal a larger decline in service industries in the more polluted regions. Taking into account that air pollution-induced regional out-migration is more pronounced among people with higher levels of education (Chen et al., 2022), our results imply that this might be due to the lower education level of the remaining labor force, which is likely to affect the overall productivity of firms in polluted regions. This is suggestive that, while polluted regions may continue to develop as manufacturing hubs, in the long run pollution may hinder a structural shift towards services, a sector that appears to be more sensitive to pollution.

Finally, we explore how the establishment of new coal plants affects the introduction of additional government infrastructure that facilitates the structural transformation of under-developed regions. Using data from the Indian government's Pradhan Mantri Gram Sadak Yojana (PMGSY) road infrastructure program, we examine whether the establishment of a coal plant promotes the expansion of road infrastructure around the area, in order to take advantage of potential SEZs. Our results indicate that coal plant establishment does not promote road infrastructure expansion. This evidence is consistent with the argument that large-scale government programs are not biasing our results.

This study makes a significant contribution to the classic literature on structural transformation (Lewis, 1954; Duarte and Restuccia, 2010; Herrendorf et al., 2013, 2014). This strand of literature delves into the drivers behind the shift of economic activities from the agricultural sector to the manufacturing or service sectors. The previous studies primarily focus on drivers such as urbanization (Michaels et al., 2012), technological progress and productivity growth (Herrendorf et al., 2015; Samaniego and Sun, 2016), trade liberalization and foreign direct investment (Teignier, 2018; Lim, 2021; Nguyen and Lim, 2023), and capital accumulation (Bustos et al., 2020). Initially highlighted by Lakshmanan (1989), recent research emphasizes that infrastructure, as public good provision, plays a pivotal role in the structural transformation process (Perez-Sebastian and Steinbuks, 2017; Timilsina et al., 2020; Moneke, 2020; Raifu et al., 2021).

Exisiting empirical studies mainly investigate resource reallocation at the firm or regional level. To the best of our knowledge, our study uniquely presents evidence of how power plant infrastructure, facilitating access to electricity resources for economic agents across sectors, leads to structural transformation within local economies, as well as how this interacts with the pollution created by the new power-generation infrastructure.

The study also contributes to the existing body of literature concerning the relationship between infrastructure development and the economies of agglomeration (Lewis and Bloch, 1998; Eberts and McMillen, 1999; Porter, 2000; McCann and Shefer, 2004; Wan and Zhang, 2018; Chaurey and Le, 2022; Dinlersoz and Fu, 2022). Earlier research primarily concentrated on the impact of road infrastructure development on firm activity within agglomerated regions. For instance, Gibbons et al. (2019) highlight the favorable effects on both employment and labor productivity at the firm level resulting from the introduction of new road infrastructure in Britain. Similarly, Banerjee et al. (2020) demonstrates how enhanced factor mobility through transportation networks led to improved regional economic outcomes in China, while Datta (2012) shows that improved road connectivity in India improves firm outcomes.

While prior studies predominantly explored the agglomeration effects of road infrastructure, which primarily improve physical connectivity for firms, our research stands out by directing attention towards power-plant infrastructure. Specifically, we delve into how the establishment of power plants in a developing economy influences the attraction of firms to surrounding areas and subsequently catalyzes transformative changes within rural economies.

This paper contributes to the growing body of literature on the roles played by power plants in driving economic development. Electricity has long been acknowledged as a pivotal factor in fostering economic growth (Stern, 1993, 2011; Shahbaz et al., 2018; Stern, 2019). In developing economies where power generation infrastructure is often limited, the scarcity of electricity frequently hampers the expansion of incumbent firms and discourages new firms from entering the market (Fried and Lagakos, 2023). This scarcity results in reduced revenues, productivity (Allcott et al., 2016), and sales (Cole et al., 2018). Additionally, Abeberese (2017) demonstrates that an increase in electricity prices in regions like India, where stable power sources are scarce, prompts firms to adopt less electricity-intensive production methods, thereby limiting opportunities for enhancing productivity. Conversely, the availability of electricity can significantly drive a country's growth by enabling firms to capitalize on productivity-enhancing technologies, many of which heavily rely on electricity (Fried and Lagakos, 2023; Abeberese et al., 2021; Rud, 2012). Access to electricity becomes a crucial factor allowing firms to leverage advancements that notably boost productivity and overall economic output.

While previous literature has mostly examined the impact of electricity supply on the firm level performance, our contribution lies in offering evidence of how the establishments of coal plants influence the economic performance of surrounding regions, particularly in the manufacturing sector.

Lastly, our paper speaks to the literature exploring the intersection of pollution and structural transformation. While manufacturing often dominates discussions on pollution, agriculture remains highly susceptible to negative externalities from pollution. The direct consequences are evident in increased emissions, which elevate the risk of crop losses due to heightened levels of greenhouse gases, ozone, or sulphur dioxide (Marshall et al., 1997). Studies such as Burney and Ramanathan (2014) have elucidated the detrimental effects of rising temperatures resulting from increased emissions of long-lived greenhouse gases, particularly highlighting significant negative impacts on crop yields, specifically in India.

Moreover, the indirect effects of air pollution are substantial, notably in diminishing farm productivity and detrimentally affecting farmers' health (Heck et al., 1982; Marshall et al., 1997; Reddy and Behera, 2006; Ramanathan and Carmichael, 2008; Aragón and Rud, 2016). Aragón and Rud (2016) discerns a reduction in agricultural productivity attributable to negative environmental externalities, illustrating how manufacturing industries' pollution can profoundly impact the living conditions of rural producers. Recent studies, including

Merfeld (2023), underscore the adverse impact of coal-plant pollution on Indian agriculture. Our study contributes significantly to this burgeoning literature by presenting evidence that pollution stemming from coal-plants can precipitate a shift away from the agricultural sector, inadvertently leading to a structural transformation pattern.

This paper is structured as follows. We first present the data and descriptive statistics in section 2 before turning to the methodology and validation in section 3. We present the main results on labor markets in section 4 and then show how exposure to pollution from coal plants mediates the structural transformation process in section 5, shedding light on the environmental consequences and their implications for the broader economic landscape. Finally, section 6 concludes.

2 Data

We use five data sets in this study. First, we use the Global Coal Plant Tracker data, which includes GPS information, to identify the exact location of coal plants in India. Second, we use both population census and economic census data from the Socioeconomic High-resolution Rural-Urban Geographic Dataset on India to measure various aspects of structural transformation at the village-level. Third, we extract nighttime lights data from the Visible Infrared Imaging Radiometer Suite (VIIRS) to measure the amount of electricity generated by the coal plant that is actually consumed by the neighboring areas and the stability of the electricity supply. Fourth, to measure the variation in regional exposure to air pollution caused by coal-fired power generation, we use daily wind data from Remote Sensing Systems' CCMP Wind Vector Analysis product was leveraged. Finally, to measure the extent of road infrastructure expansion in areas surrounding coal plants, we pull road construction data from India's Pradhan Mantri Gram Sadak Yojana (PMGSY).

Coal Plant Data We first identify the location of all coal plants in India using data from the Global Coal Plant Tracker (GCPT).[2] This data provides information on coal-fired power plants around the world that produce 30 megawatts or more, including India. Specifically, the GCPT provides information on (i) all coal-fired power plants currently in operation, (ii) all new plants proposed, and (iii) all plants retired since 2000. Our study is limited to India and utilizes the GPS coordinates of the location of all coal-fired power plants in India.

Population Census and Economic Census in India For data on structural transformation, we use the recently released Socioeconomic High-resolution Rural-Urban Geographic Dataset on India, or SHRUG, introduced by Asher et al. (2021).[3] The SHRUG database includes a village-level shapefile for all of India. Importantly, the database creators have matched these village polygons to information from different censuses. Specifically, they include village identifiers for information from the 1990, 1998, 2005, and 2013 economic censuses as well as the 1991, 2001, and 2011 population censuses. Since these are census data, we only have access to aggregate numbers for each village, not the individual data. In addition, Asher et al. (2021) have harmonized data to match across different census years. However, this leads to some complications.

First and foremost, the economic census includes only firms, not household businesses. We calculate employment rates in these firms by dividing the number of people employed by the number of people in the village. Since the number of people employed by the firms in the economic census is relatively low, the estimated employment rates are also low. In other words, these are not employment rates as commonly defined since they do not include the large number of people who are self-employed, for example. However, we can still use these data to examine the impact of coal plants on employment in firms. We can also examine the impact on the number of firms in the village, which is the number of firms in the economic

[2]Data sourced from the Global Coal Plant Tracker (GCPT), available at: https://globalenergymonitor.org/projects/global-coal-plant-tracker

[3]Data sourced from SHRUG, available at: https://www.devdatalab.org/shrug

census. Importantly, agricultural firms are not included in the economic census harmonized data due to inconsistencies in industry coding across censuses, which also undercounts the overall employment rate. Nonetheless, we can still examine the impact of coal plants on employment in manufacturing and services in larger firms.

The population census includes information on population counts in 1991, 2001, and 2011. We match the closest population census to the economic census in order to calculate employment rates (with the caveat noted above). In addition, the population census also includes information on the number of people employed in agriculture, which we use to complement the industry results from the economic census. Finally, we use information on the number of people who are literate in the village as well as whether the village has power for any given year. The latter is a dummy variable that is one if the village has power and zero otherwise.

With the census matched to a village shapefile, we then calculate the overlap between coal plants and village centroids. Specifically, we define treated villages as village centroids within 50km of a coal plant. We define this variable separately for each census year (and separately for the population and economic censuses). Due to data availability, we use the population of individuals over seven years of age, meaning the employment rates are underestimated of the rates for the working-age population. Since we are interested in structural transformation, we restrict estimation to "villages" with less than 100,000 people. This restriction drops just 0.05 percent of villages from the sample.

We present summary statistics for the population census and economic census in appendix Table A1 and appendix Table A2, respectively. The increase in coal plants is clear with both censuses; while only 17 percent of villages are located near a coal plant in 1990/1991, that number increases to more than 30 percent by 2013. Population increases by almost 40 percent between the 1991 and 2011 census, while the literacy rate almost doubles for those above seven years of age. We also see some signs of structural transformation for the population as a whole. The proportion of people engaged in agriculture decreases markedly between the first and last censuses, as does the raw number of individuals.

As mentioned above, the employment rates calculated with the economic census are not traditional employment rates. Instead, it is the proportion of the population that is employed by a firm in the economic census, which is a small subset of all employment types (employment in large firms is defined similarly). The industry rates, however, are calculated as the proportion of people employed in one of those firms, so they are higher. We can see some signs of India moving from manufacturing to services; the proportion of people employed in manufacturing decreases by around half of its initial value, while the proportion of people employed in services increases by more than 10 percentage points.

Air Pollution Exposure Data One key contribution of our paper is understanding how pollution patterns mediate structural transformation. We pull daily wind data from Remote Sensing Systems' CCMP Wind Vector Analysis product (Mears et al., 2022).[4] The data include four observations per day, at 0.25 degree resolution. Due to the time it takes to pull the daily data, we do not pull data for the entire sample period. Instead, we pull data for 1,461 days – four full years – randomly selected between 1990 and 2013. We calculate the number of days in which the wind is blowing from the location of a coal plant to within five degrees of the centroid for each village. We then use this value to calculate the proportion of days in which this is true. We find the top quartile of this proportion and call it "high exposure." Note that this variable is zero for a village *before* a coal plant opens. It is missing for a village that is *never* near a coal plant.

Nighttime Lights Data We also use nighttime lights from the Visible Infrared Imaging Radiometer Suite, more commonly referred to as VIIRS,[5] which is a satellite-based sensor that measures light emissions at night. One downside to using VIIRS is that it is only available

[4]Data sourced from Remote Sensing Systems' CCMP Wind Vector Analysis product, available at https://www.remss.com/measurements/ccmp/.

[5]Data sourced from the Visible Infrared Imaging Radiometer Suite, available at: https://www.nesdis.noaa.gov/our-satellites/currently-flying/joint-polar-satellite-system/visible-infrared-imaging-radiometer-suite-viirs

back to 2012. However, recent research indicates that VIIRS is a better proxy for economic outcomes than the older DMSP data (Gibson et al., 2021), so we opt to use the former.

Road Construction Data Finally, we use georeferenced data on road construction from the Pradhan Mantri Gram Sadak Yojana, or PMGSY, which is a government program aimed at building rural roads.[6] The data include the length of roads built in each year, which we match to villages using the shapefile provided by the program. We also calculate the cumulative length of roads built up to a given year. Our main goal with these data is to show that a well-known infrastructure project is not driving any results we observe with coal plants.

3 Methodology

We are interested in estimating the effect of a coal plant opening within 50km of a village. Consider a regression of the following form:

$$y_{it} = \alpha_i + \gamma_t + \beta coal_{it} + \varepsilon_{it}, \tag{1}$$

where y_{it} is some outcome of interest – like the proportion of the population employed in manufacturing; α_i is village fixed effects; γ_t is year (or census wave) fixed effects; and β is the coefficient of interest, which is the effect of a coal plant opening within 50km of a village. This is a traditional two-way fixed effects estimator, which recent research has shown can be biased under certain circumstances (see, for example, De Chaisemartin and d'Haultfoeuille (2020) and Goodman-Bacon (2021), as well as the excellent review in Roth et al. (2023)). We use the `did2s` package in R (Butts and Gardner, 2021), which implements a two-way fixed effects estimator, as well as event study estimates. The package calculates identical point estimates as Borusyak et al. (2021), but with slightly different standard errors. Throughout

[6] https://pmgsy.nic.in/

the results, we cluster results at the village level to account for serial correlation in outcomes across time.

3.1 Electricity Power Supply

Before examining how coal plant establishment affects changes in various aspects of economic structure, we first validate whether coal plant establishment increases electricity supply at the village level. Next, we go beyond the finding that coal plants increase access to electricity and examine how coal plant establishment affects actual electricity use in villages and the reliability of electricity supply. This second question is particularly important because a large body of recent literature suggests that consistent electricity supply is particularly important for firm productivity in developing countries (Abeberese, 2017; Cole et al., 2018; Abeberese et al., 2021; Sedai et al., 2021; Fried and Lagakos, 2023). In addition, in many developing countries, electricity generated by power plants is often poorly distributed to homes and businesses due to a lack of wire infrastructure.

However, in regions such as rural India, in particular, long-term data on electricity availability at the village level is not available, which brings us back to the core issue of data availability. To overcome this problem, we utilize nighttime lights data. Specifically, we take monthly data on night lights in each village from VIIRS. We then aggregate this to an annual level to create an annual panel of villages. We measure the quantitative supply of electricity by calculating the annual within-village average of night lights. We also calculate the standard deviation and assume that the lower the standard deviation, the more consistent and reliable the electricity supply.

Table 1 reports the estimation results. As shown in the first column using census data, villages within 50 kilometers of a coal plant have better access to electricity. The probability of a village having electricity increased by 7.5 percentage points after a nearby coal plant was built, which is more than 15% higher than the average for villages not located near a coal plant in a given year.

Table 1: The Effect of Coal Plants on Power Supply

	Power	Nightlights	
		mean	sd (log)
	(1)	(2)	(3)
Coal plant within 50km	0.075***	0.056***	-0.013***
	(0.004)	(0.005)	(0.002)
Untreated mean	0.487	0.775	-1.291
Observations	1,164,672	3,042,032	3,042,032

Note: Results use the did2s package in R, which includes village and wave fixed effects. Standard errors are in parentheses and clustered at the village level. The first column indicates whether the village has a coal plant within 50km. The second column is related to power. The next two columns are related to nightlights.
* p<0.10 ** p<0.05 *** p<0.01

The increased access to electricity in these villages is also consistent with the actual use of electricity at night. The second column shows the increase in average nighttime light levels after the coal plant was built. The overall increase is about 7% of the untreated average, which indicates a significant increase in nighttime light. The increase in mean nightlights could lead to higher variance in nightlights within a year. Despite this, as shown in the third column, the within-year standard deviation of nighttime illumination decreases after the coal plant is built. While this is not a perfect measure of power consistency and reliability, it still provides evidence that coal plant construction increases the consistency of power, potentially leading to increased productivity and structural change in firms.

4 Results

We now turn to the impact of coal plant construction on local labor markets. As reported in Table 2, we find that the overall employment rate decreases by 0.2 percentage points, but this is a small effect of only 0.4%, compared to the untreated average. This decrease in employment rates is accompanied by an increase in population of about 2%. Meanwhile, the literacy rate, which is a proxy for the quality of the labor force, increases by about 0.4 percentage points, or about 0.8 percent compared to villages located more than 50km from a power plant, suggesting that the power plant helped supply more labor to the local economy and ensure a more skilled labor force.

Table 2: Coal Plants and Labor Supply

	Emp. rate (1)	Pop (log) (2)	Lit. rate (3)
Coal plant within 50km	-0.002***	0.020***	0.004***
	(0.001)	(0.001)	(0.001)
Untreated mean	0.533	6.306	0.531
Observations	1,434,055	1,434,084	1,434,084

Note: Results use the did2s package in R, which includes village and wave fixed effects. Standard errors are in parentheses and clustered at the village level. The data are from the population census. The first column is a dummy for whether the village has electricity. The second column is log village population. The third column is the standardized literacy rate. * p<0.10 ** p<0.05 *** p<0.01

4.1 Sectoral Reallocation

So far, we have shown that the establishment of a coal plant can mark a new turning point in the local economy by demonstrating its impact on the supply of electric energy and labor at the village level. However, it remains to be seen whether this turning point can lead to a structural transformation of the local economy. In this section, we discuss one of the most important aspects of multifaceted structural transformation: the reallocation of labor across sectors. As the literature has shown, the transition from agriculture to manufacturing is a typical developmental stage that marks the transition of underdeveloped countries to relatively more advanced economies.

The estimation results are reported in Table 3. We find that the establishment of a coal plant in a village reduces the share of agricultural employment in the village as well as the actual number of workers employed in agriculture. The opening of a coal plant decreases the proportion of people in the village who are cultivators or agricultural laborers by around two percentage points, which is a 3.6 percent decrease relative to the mean in untreated villages. We also see a decrease in the total number of people engaged in agriculture of around five percent as well as a small absolute – but large relative – decrease in the number of people engaged in relatively low-productivity and informal household manufacturing.

Table 3: Coal Plant and Employment in Agriculture and Household Manufacturing

	Agriculture (prop) (1)	Agriculture (log) (2)	HH Manu. (prop) (3)
Coal plant within 50km	-0.022***	-0.050***	-0.003***
	(0.002)	(0.004)	(0.000)
Untreated mean	0.611	4.928	0.017
Observations	1,433,671	1,408,509	1,394,511

Note: Results use the did2s package in R, which includes village and wave fixed effects. Standard errors are in parentheses and clustered at the village level. The second column is the proportion of people in the village who are cultivators or agricultural laborers. The third column is the total number of people (log) in the village who are employed. The fourth column is the proportion of people in the village who engage in household manufacturing.
* p<0.10 ** p<0.05 *** p<0.01

Although not addressed in our study, there are several potential explanations for the decline in the agricultural sector due to the establishment of coal plants in accordance with the existing literature. First, competition for water resources and local soil pollution are among the main explanations for current difficulties facing the agricultural sector (Jain et al., 2021) and coal power plants require significant amounts of water for cooling.[7] For small-scale farmers in India, who are facing increasing shortages of agricultural water due to climate change over time (*ibid.*), the large-scale, low-cost use of industrial water by coal plants may cause serious repercussions. Second, the disposal of coal ash, a byproduct of coal combustion, or improperly stored coal ash, contaminates groundwater and soil with heavy metals and

[7]See, for example, information from the U.S. Department of Energy that may explain how coal plants can affect water usage: https://netl.doe.gov/research/Coal/energy-systems/gasification/gasifipedia/water-usage

other toxins (Cherry and Guthrie, 1977). However, the results below suggest that much of this decline may be driven by the growth in manufacturing.

We next look at the effect on the non-agricultural sector using the economic census data. Table 4 presents results for employment patterns in firms from the economic census. In the first column, we see that employment in firms decreases by 0.2 percentage points, consistent with the decrease seen in the population census (Table 2). We note that the small untreated mean for the employment rate is driven by the fact that the economic census only includes firms – not self-employment – and the fact that the harmonized data exclude agricultural firms. The other means are calculated using the proportion of people in the village who are employed in an econmic census firm, leading to higher values.

Table 4: Coal Plants and Employment in Manufacturing and Service Firms

	Emp. rate (1)	Manufacturing (2)	Service (3)	In firm of 21+ people (4)
Coal plant within 50km	-0.002*	0.036***	-0.042***	0.059***
	(0.001)	(0.004)	(0.005)	(0.006)
Untreated mean	0.057	0.237	0.741	0.031
Observations	1,604,998	1,522,711	1,522,711	1,522,313

Note: Results use the did2s package in R, which includes village and wave fixed effects. Standard errors are in parentheses and clustered at the village level. The data are from the economic census and does not include agricultural firms or household firms. The first column is the standardized employment rate. The second column is the standardized rate of people in manufacturing. The third column is the standardized rate of people in services. The last column is the proportion of people in the village who are employed in firms of more than 20 people.
* p<0.10 ** p<0.05 *** p<0.01

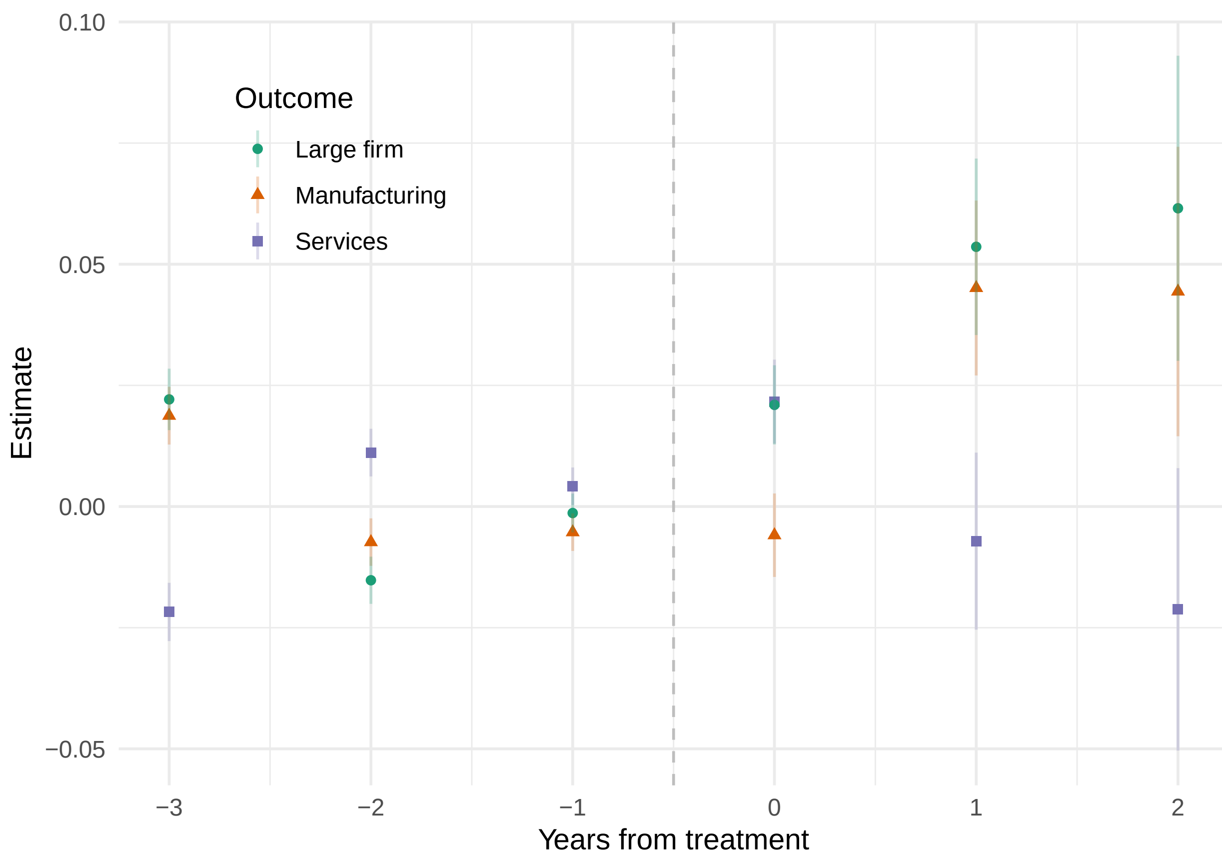
Interestingly, as shown in the second column, we find that the establishment of a coal plant has the effect of increasing manufacturing employment by 3.6 percentage points, or almost 15 percent relative to the untreated mean. This increase is driven, presumably, by the decrease in agricultural employment as well as the decrease in people employed in service firms (column 3). In the fourth column, we show that, in particular, the employment rate of large non-agricultural firms employing 21 or more workers increases by 5.9 percentage points. The opening of a coal plant almost triples the proportion of people employed in larger firms relative to the untreated mean, which could lead to larger increases in productivity (Poschke, 2018).

Contrary to overall country-wide trends, the shift away from agriculture and toward non-agricultural sectors did not ultimately lead to the expansion of the service sector. In column (3), we find that the introduction of coal power reduced standardized employment in service firms by 4.2 percentage points. However, it is difficult to argue that the introduction of coal power is a reversal of the structural transformation trend based on a decline in services and a retreat into manufacturing. We note that the service sector in developed countries is dominated by higher-order services such as finance, telecommunications, retail, and healthcare, whereas the rural Indian economy is dominated by more basic services. Furthermore, the share of services in the rural Indian economy as a whole is relatively small compared to agriculture (although it is large when using only the economic census). The decrease in services is in the opposite direction of the aggregate trends for the country as a whole, which has seen a decrease in manufacturing employment and an increase in services employment (Table A1 and Table A2 in the appendix).

Table A3 in the appendix presents results using firm counts for each village. The data do not break down firm size across sectors, however, so we focus only on firm size. We see overall decreases in firms but this is driven by firms of less than 21 people. On the other hand, consistent with the results in Table 4, we see very large relative increases in the number of large firms of 21 or more people; treated villages see the number of large firms increase by 20-fold, indicating that access to electricity is an important condition for large firm growth.

As supportive evidence of the identification assumptions, we also present event studies of the effects of coal plants on firm employment, using the four waves of the economic census. As seen in Figure 1, the results do not seem to be driven by pre-treatment trends. Overall employment in different firm types does not trend systematically prior to the opening of a coal plant. Second, the results seem to lag the opening of a coal plant slightly. Manufacturing, for example, is relatively stable through the first wave after treatment, but then increases dramatically in the following two waves. We see the exact same pattern for employment in large firms and the opposite pattern for employment in services, which is suggestive evidence that these changes are intimately related to one another.

Figure 1: Event study (economic census)



Note: Event study results are calculated using the did2s function in R. Time to treatment is based on waves of the economic census.

4.2 Gender gaps

We further explore one aspect of structural transformation: the gender gap in the labor market. In developing countries, women are often stuck in household agriculture or informal domestic work without equal access to labor, making it difficult for women's labor to flow into manufacturing. Under the assumption that employment in firms is more remunerative than other forms of employment common in India, we break down changes in employment for men and women separately.

Table A4 in the appendix shows that men appear to benefit more from the increase in firms, at least in absolute terms. The proportion of men employed in firms increases by 6.6 percentage points following the construction of a coal plant, while the propotion of women employed in firms increases by 3.6 percentage points. However, in relative terms, this actually decreases the gender gap in firm employment, as the value for women more than doubles. Using the untreated means, 2.75 men are employed for every woman employed. After the increase, however, this number drops to 2.26.

The labor force participation gap between men and women is one of the largest in the world (Andres et al. 2017). Recent evidence also suggests that access to electricity can decrease this gap Dinkelman (2011); Sedai et al. (2021). We do not see any clear evidence of large changes in overall employment rates in the population census, however (Table A5 in the appendix).

5 Pollution and Structural Transformation

In the previous section, we showed that the establishment of a coal plant causes the community to change its industrial structure to become more manufacturing-oriented. We also find that the construction of coal plants causes changes such as the provision of electricity, an increase in the total labor force, a shift away from agriculture and services toward manufacturing, and a small reduction in the gender gap in firm employment.

However, while these electricity-driven changes are overwhelmingly positive, they ignore an important aspect of power derived from fossil fuels: pollution. Coal-fired power plants emit significant air pollutants, unlike other forms of power generation such as hydro, wind, and nuclear power plants. These emissions include pollutants such as sulfur dioxide (SO2), nitrogen oxides (NOx), and particulates. This causes extreme air pollution in communities, including acid rain, smog, and the formation of ozone in the atmosphere.[8]

The goal of this section is to better understand how air pollution as a result of new coal-fired power generation – that is, negative externalities produced by electricity production – affects structural transformation and, more broadly, whether it fosters or inhibits it. In particular, we want to test the hypothesis that regions that are relatively more exposed to air pollution from new coal power plants may experience different patterns of economic restructuring than other regions. If this hypothesis is valid, it suggests that government policies should be more responsive to vulnerable regions that are exposed to the resulting environmental damage. Understanding the effects in the current context can also improve our understanding of how pollution affects the development process more generally.

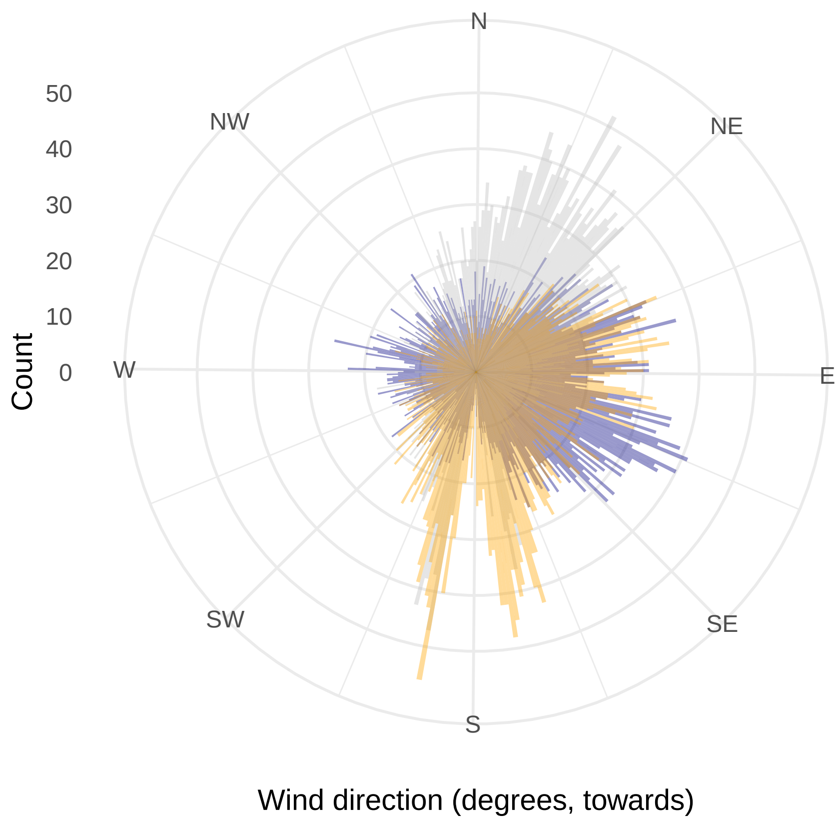
5.1 Measuring Exposure to Air Pollution

We employ a novel technique to measure the air pollution emitted by the establishment of new coal plants and their subsequent electricity generation. First, we find the prevailing wind directions at the location of each coal plant and use this to define an exposure variable for each village within 50km of the coal plant. We then calculate the proportion of days in which the wind is blowing from the location of the coal plant to within five degrees of the centroid for each village – only for villages ever located within 50km of a coal plant – and then find the villages most likely to be located downwind from the coal plant. We define a "high exposure" variable for the top quartile of this exposure variable. Note that this variable is zero for a village *before* a coal plant opens and it is missing for a village that is *never* near a coal plant. We can use this variable to look at differential changes for high-exposure villages relative to low-exposure villages.

[8]While scrubber installation can reduce the number of pollutants emitted by power plants, many power producers in India continue to operate without installation. See, for example, coverage in the press, such as https://thewire.in/business/why-indias-deadly-coal-power-plants-continue-polluting. Cropper et al. (2018) estimate that the installation of scrubbers could avoid 13,000 premature deaths and 320,000 DALYs annually.

Figure 2 shows an example of this wind direction variable for three separate coal plants. Each coal plant has its own local wind variation, which leads to different villages being downwind from each coal plant. Across all villages, the top quartile of exposure is 0.162, meaning that the villages are downwind from the coal plants on more than 16 percent of days, on average. For comparison, the median village is downwind from a coal plant less than one-third of that amount, while the first quartile of villages is never downwind from the coal plant.

Figure 2: Examples of prevailing wind directions for three coal plants



Note: The figure shows the polar histogram of wind direction at the location of three coal plants across 1,461 randomly selected days between 1990 and 2013.

5.2 Non-employment Outcomes

Before looking at the impact on structural change by sector, we provide an overview of non-employment outcomes in areas with greater exposure to air pollution, using the population census. As shown in Table 5, we find that areas with greater exposure to air pollution from coal power plants have relatively less access to electricity, smaller populations, and lower literacy rates. Note that this is not a reduction in absolute terms, but relative to less exposed villages that are still within 50km of a coal plant. In light of our findings in the previous section, this suggests that households in polluted areas tend to move to other areas and benefit less from coal-fired power generation. It is also consistent with existing studies that show that pollution negatively affects the quality of labor. Chen et al. (2022), for example, show that relatively educated people are more likely to migrate in response to increases in pollution, which could explain our results.

Table 5: Air Pollution Exposure and Non-employment Outcomes

	Power (1)	Pop (log) (2)	Lit. rate (3)
Top quartile of exposure	-0.023***	-0.012***	-0.005***
	(0.006)	(0.002)	(0.001)
Untreated mean	0.474	6.423	0.534
Observations	321,457	416,498	416,498

Note: Results use the did2s package in R, which includes village and wave fixed effects. Standard errors are in parentheses and clustered at the village level. Only villages ever-located within 50km of a coal plant are included. Exposure is defined as zero prior to the opening of the coal plant so that the estimate can be interpreted as the difference in outcomes for exposed villages relative to unexposed villages after the opening of a coal plant. The data are from the population census. The first column is an indicator for whether the village has power. The second column is the (log of) total people living in the village. The third column is the proportion of people (over 7) who are literate.
* $p<0.10$ ** $p<0.05$ *** $p<0.01$

5.3 Out of Agriculture, Toward Manufacturing

We first look at the impact of air pollution on the agricultural sector and present the result in Table 6. We show that higher air pollution exposure leads to an exodus of workers from the agricultural sector in regions with more severe air pollution exposure. After the coal plant is built, the proportion of agricultural workers in exposed villages drops by four percentage points, which is around 7% of the average for non-exposed areas.

Table 6: Air pollution exposure and individual-level employment

	Agriculture (1)	Marg. Workers (2)	HH Manu. (3)
Top quartile of exposure	-0.040***	0.030***	-0.001*
	(0.002)	(0.002)	(0.001)
Untreated mean	0.606	0.224	0.02
Observations	416,376	411,787	402,165

Note: Results use the did2s package in R, which includes village and wave fixed effects. Standard errors are in parentheses and clustered at the village level. Only villages ever-located within 50km of a coal plant are included. Exposure is defined as zero prior to the opening of the coal plant so that the estimate can be interpreted as the difference in outcomes for exposed villages relative to unexposed villages after the opening of a coal plant. The data are from the population census. The first column is the proportion of people in the village who are engaged in agriculture as their main occupation. The second column is the proportion of people in the village who are classified as marginal workers. The third column is the proportion of people in the village who are engaged in household manufacturing.
* p<0.10 ** p<0.05 *** p<0.01

We also find that the proportion of households engaged in temporary employment, which is categorized as marginalized workers, increases.[9] Given the damage that air pollution inflicts on public health and the cost to the agricultural sector by disrupting ecosystems, our results can be interpreted as an exodus of workers from agriculture in areas that are more affected by coal-fueled pollution.

Next, we turn our attention to the non-agricultural sector. Here, we ask two related questions: Do agricultural workers displaced by exposure to air pollution from coal plants flow into the local non-agricultural sector? If so, do they go into manufacturing or services? Using the economic census data, we report our findings in Table 7. As shown in column (1), the share of employment in manufacturing firms increased in areas more exposed to pollution.

[9]The term "marginal workers" is defined as "a person who might have done some work any time during the previous year, but not for the major part of the year." For more details, see https://www.ilo.org/ilostat-files/SSM/SSM5/E/IN.html

By looking at columns (3) and (4), this increase is much more pronounced for large firms (21+ employees) than for small firms.

Table 7: Air pollution exposure and firm employment

	Manu. (1)	Services (2)	Large firm (3)	Private firm (4)
Top quartile of exposure	0.047***	-0.052***	0.064***	0.007*
	(0.006)	(0.007)	(0.008)	(0.004)
Untreated mean	0.237	0.741	0.031	0.787
Observations	478,985	478,985	478,985	478,985

Note: Results use the did2s package in R, which includes village and wave fixed effects. Standard errors are in parentheses and clustered at the village level. Only villages ever-located within 50km of a coal plant are included. Exposure is defined as zero prior to the opening of the coal plant so that the estimate can be interpreted as the difference in outcomes for exposed villages relative to unexposed villages after the opening of a coal plant. The data are from the economic census and does not include agricultural firms or household firms. The first column is the proportion of people in the village employed in manufacturing firms. The second column is the proportion of people in the village employed in services firms. The third column is the proportion of people in the village employed in firms of more than 20 people. The fourth column is the proportion of people in the village employed in private firms.
* p<0.10 ** p<0.05 *** p<0.01

Collectively, these two findings suggest that the influx of workers into manufacturing, which is dominated by large firms, is more pronounced in regions that are more exposed to air pollution from coal-fired power generation. This is despite the decrease in access to electricity in these areas. Table A6 in the appendix supports this interpretation. The table shows that the overall number of firms decrease in the more polluted areas relative to the less polluted areas and that this decrease is driven by firms with 20 or fewer employees. On the other hand, we see a large relative increase in the number of firms with 21 or more employees, though we caution that this estimate is very imprecise.

What explains these results? One potential mechanism is migration. While the population shrinks, those who remain are less likely to work in agriculture and more likely to work in manufacturing. From the perspective of a business owner, staying in a polluted area may have few downsides, while households may be more likely to move due to pollution. Similarly, firm location may be more rigid than households and firms may find it more difficult to relocate, given the costs of relocation, leading to a persistence of manufacturing firms in polluted areas. This could lead to long-run decreases in productivity driven by exposure to pollution (Fu et al., 2021).

Meanwhile, as shown in column (2) of Table 7, the stronger decline in the service sector in these regions suggests that while polluted regions might continue to develop as manufacturing hubs, in the long run pollution could be stifling further structural transformation into the service sector, either because the sector is more vulnerable to pollution or because service firms find it easier to move. Insofar as services firms also tend to be smaller than manufacturing firms, the results on firm size underscore the possible long-term consequences of pollution.

It is possible that coal plants are placed such that certain areas are systematically located downwind. As a final check, we present the event study results for the outcomes in Table 7 in Figure A3 of the appendix. Starting from two years before treatment, the results are relatively stable for all outcomes. As with the previous results, it is also clear that results do not happen immediately; instead, they appear to lag by one wave of the census, as only in the second treatment wave do we begin to see large increases in employment in manufacturing firms and in large firms. This is consistent with the idea that the results we observe are not driven by pre-treatment trends.

5.4 Are the Effects Driven by Concurrent Government Programs?

In many developing countries, the introduction of one form of infrastructure brings additional government infrastructure to the area. This can be achieved, for example, by building special economic zones (SEZs) in particular locations to leverage economies of scale. In this section, we examine how the establishment of new coal plants affects the government's introduction of infrastructure that facilitates structural transformation in underdeveloped regions. In particular, we focus on the expansion of road network infrastructure. Many previous studies have shown that the expansion of local road networks plays an important role in sustained regional economic development. Expanded roads accelerate regional development by improving connectivity between rural and urban areas, enabling the efficient movement of people and goods. Road expansion is essential for trade, enabling businesses to reach wider markets and promoting economic integration, and previous research has found positive effects of this type of explansion (Datta, 2012; Asturias et al., 2019; Adukia et al., 2020).

We use data on India's large road construction program, Pradhan Mantri Gram Sadak Yojana (PMGSY),[10] available from the India goverment to analyze whether road construction increases concurrently with the opening of a coal plant. We report these results in Table 8. Interestingly, we find that in regions where coal plants were built, road expansion as part of the government's infrastructure building program decreased. In addition, the event study results indicate that these results may be driven by differential pre-trends. Figure A2 in the appendix presents these results. The length of total roads built, in particular, appears to be decreasing consistently from around six or seven years prior to the construction of a coal plant, while the length of roads built in a given year does not show any consistent patterns, either before or after the construction of a coal plant.

[10]"The objective of the Pradhan Mantri Gram Sadak Yojana (PMGSY) is to provide good all-weather road connectivity to unconnected Habitations. Rural Road Connectivity is not only a key component of Rural Development by promoting access to economic and social services and thereby generating increased agricultural incomes"https://vikaspedia.in/social-welfare/rural-poverty-alleviation-1/schemes/pradhan-mantri-gram-sadak-yojana

Table 8: Coal Plants and Roads Built (km)

	Roads (year) (1)	Roads (total) (2)
Coal plant within 50km	-0.003***	-0.034***
	(0.001)	(0.004)
Untreated mean	0.053	0.548
Observations	9,371,985	9,371,985

Note: Results use the did2s package in R, which includes village and wave fixed effects. Standard errors are in parentheses and clustered at the village level. The first column is the length (km) of roads built in a given year through the government's PMGSY program. The second column is the cummulative length of roads built up to a given year. * p<0.10 ** p<0.05 *** p<0.01

We find that the establishment of coal power plants does not lead to an expansion of road infrastructure, but rather to a decline after a few years. In other words, coal plant establishment is negatively correlated with the Indian government's road construction infrastructure program, PMGSY, meaning that coal plant establishment unexpectedly reduces rather than expands the government's construction of new road infrastructure. We interpret this result as evidence that government infrastructure does not increase following the construction of a coal plant, which supports the identification assumptions.

6 Conclusion

This study explores the impact of coal power plant establishment on structural change at the village level in India. We find that the proximity of a coal plant improves electricity supply, increases population, and improves literacy rates. In particular, we find changes that lead to a shift in employment from agriculture to manufacturing, particularly to formal manufacturing enterprises. The study also observes a narrowing of the gender gap in non-agricultural enterprises, indicating positive changes in labor markets at the village level.

This study also examines unexpected structural changes resulting from the establishment of coal power plants, focusing on areas exposed to air pollution. Areas more exposed to air pollution have lower access to electricity, smaller populations, and lower literacy rates, suggesting migration from polluted areas. Towns with higher air pollution experience an exodus of agricultural workers, a decline in small-scale manufacturing, and an increase in vulnerable day laborers. Manufacturing employment increases in polluted areas, but the decline in services suggests that there may be long-term barriers to a shift to services. The study also examines the impact on government infrastructure, finding that the establishment of coal plants does not promote the continued expansion of road infrastructure, potentially limiting local economic development.

Our study reveals a structural transformation through an increase in the manufacturing sector following the establishment of coal plants, but also a decline in the agricultural industry. This highlights the tragic aspect that while the manufacturing sector expands through relatively cheap electricity generation, the agricultural sector is driven out due to environmental pollution.

References

Abeberese, Ama Baafra, "Electricity cost and firm performance: Evidence from India," *Review of Economics and Statistics*, 2017, *99* (5), 839–852.

_ **, Charles Godfred Ackah, and Patrick Opoku Asuming**, "Productivity losses and firm responses to electricity shortages: Evidence from Ghana," *The World Bank Economic Review*, 2021, *35* (1), 1–18.

Adukia, Anjali, Sam Asher, and Paul Novosad, "Educational investment responses to economic opportunity: evidence from Indian road construction," *American Economic Journal: Applied Economics*, 2020, *12* (1), 348–376.

Agrawal, Madhoolika, "Effects of air pollution on agriculture: an issue of national concern," *National Academy Science Letters*, 2005, *28* (3/4), 93–106.

Allcott, Hunt, Allan Collard-Wexler, and Stephen D O'Connell, "How do electricity shortages affect industry? Evidence from India," *American Economic Review*, 2016, *106* (3), 587–624.

Aragón, Fernando M and Juan Pablo Rud, "Polluting industries and agricultural productivity: Evidence from mining in Ghana," *The Economic Journal*, 2016, *126* (597), 1980–2011.

Asher, Sam, Tobias Lunt, Ryu Matsuura, and Paul Novosad, "Development Research at High Geographic Resolution: An Analysis of Night Lights, Firms, and Poverty in India using the SHRUG Open Data Platform," *The World Bank Economic Review*, 2021.

Asturias, Jose, Manuel García-Santana, and Roberto Ramos, "Competition and the welfare gains from transportation infrastructure: Evidence from the Golden Quadrilateral of India," *Journal of the European Economic Association*, 2019, *17* (6), 1881–1940.

Banerjee, Abhijit, Esther Duflo, and Nancy Qian, "On the road: Access to transportation infrastructure and economic growth in China," *Journal of Development Economics*, 2020, *145*, 102442.

Borusyak, Kirill, Xavier Jaravel, and Jann Spiess, "Revisiting event study designs: Robust and efficient estimation," *arXiv preprint arXiv:2108.12419*, 2021.

Burney, Jennifer and V Ramanathan, "Recent climate and air pollution impacts on Indian agriculture," *Proceedings of the National Academy of Sciences*, 2014, *111* (46), 16319–16324.

Bustos, Paula, Gabriel Garber, and Jacopo Ponticelli, "Capital accumulation and structural transformation," *The Quarterly Journal of Economics*, 2020, *135* (2), 1037–1094.

Butts, Kyle and John Gardner, "{did2s}: Two-stage difference-in-differences," *arXiv preprint arXiv:2109.05913*, 2021.

Chaisemartin, Clément De and Xavier d'Haultfoeuille, "Two-way fixed effects estimators with heterogeneous treatment effects," *American Economic Review*, 2020, *110* (9), 2964–2996.

Chaurey, Ritam and Duong Trung Le, "Infrastructure maintenance and rural economic activity: Evidence from India," *Journal of Public Economics*, 2022, *214*, 104725.

Chen, Shuai, Paulina Oliva, and Peng Zhang, "The effect of air pollution on migration: Evidence from China," *Journal of Development Economics*, 2022, *156*, 102833.

Cherry, DS and RK Guthrie, "TOXIC METALS IN SURFACE WATERS FROM COAL ASH," *Journal of the American Water Resources Association*, 1977, *13* (6), 1227–1236.

Cole, Matthew A, Robert JR Elliott, Giovanni Occhiali, and Eric Strobl, "Power outages and firm performance in Sub-Saharan Africa," *Journal of Development Economics*, 2018, *134*, 150–159.

Covert, Thomas, Michael Greenstone, and Christopher R Knittel, "Will we ever stop using fossil fuels?," *Journal of Economic Perspectives*, 2016, *30* (1), 117–138.

Cropper, Maureen L, Sarath Guttikunda, Puja Jawahar, Kabir Malik, and Ian Partridge, "Costs and benefits of installing flue-gas desulfurization units at coal-fired power plants in India," *Disease Control Priorities, Third Edition (Volume 7): Injury Prevention and Environmental Health*, 2018.

Datta, Saugato, "The impact of improved highways on Indian firms," *Journal of Development Economics*, 2012, *99* (1), 46–57.

Dinkelman, Taryn, "The effects of rural electrification on employment: New evidence from South Africa," *American Economic Review*, 2011, *101* (7), 3078–3108.

Dinlersoz, Emin M and Zhe Fu, "Infrastructure investment and growth in China: A quantitative assessment," *Journal of Development Economics*, 2022, *158*, 102916.

Duarte, Margarida and Diego Restuccia, "The role of the structural transformation in aggregate productivity," *The quarterly journal of economics*, 2010, *125* (1), 129–173.

Eberts, Randall W and Daniel P McMillen, "Agglomeration economies and urban public infrastructure," *Handbook of regional and urban economics*, 1999, *3*, 1455–1495.

Fisher-Vanden, Karen, Erin T Mansur, and Qiong Juliana Wang, "Electricity shortages and firm productivity: evidence from China's industrial firms," *Journal of Development Economics*, 2015, *114*, 172–188.

Fletcher, Erin, Rohini Pande, and Charity Maria Troyer Moore, "Women and work in India: Descriptive evidence and a review of potential policies," 2017.

Fried, Stephie and David Lagakos, "Electricity and firm productivity: A general-equilibrium approach," *American Economic Journal: Macroeconomics*, 2023, *15* (4), 67–103.

Fu, Shihe, V Brian Viard, and Peng Zhang, "Air pollution and manufacturing firm productivity: Nationwide estimates for China," *The Economic Journal*, 2021, *131* (640), 3241–3273.

Gibbons, Stephen, Teemu Lyytikäinen, Henry G Overman, and Rosa Sanchis-Guarner, "New road infrastructure: the effects on firms," *Journal of Urban Economics*, 2019, *110*, 35–50.

Gibson, John, Susan Olivia, Geua Boe-Gibson, and Chao Li, "Which night lights data should we use in economics, and where?," *Journal of Development Economics*, 2021, *149*, 102602.

Goodman-Bacon, Andrew, "Difference-in-differences with variation in treatment timing," *Journal of Econometrics*, 2021, *225* (2), 254–277.

Heck, Walter W, OC Taylor, Richard Adams, Gail Bingham, Joseph Miller, Eric Preston, and Leonard Weinstein, "Assessment of crop loss from ozone," *Journal of the Air Pollution Control Association*, 1982, *32* (4), 353–361.

Herrendorf, Berthold, Christopher Herrington, and Akos Valentinyi, "Sectoral technology and structural transformation," *American Economic Journal: Macroeconomics*, 2015, *7* (4), 104–133.

_ , Richard Rogerson, and Akos Valentinyi, "Two perspectives on preferences and structural transformation," *American Economic Review*, 2013, *103* (7), 2752–2789.

_ , _ , and _ , "Growth and structural transformation," *Handbook of economic growth*, 2014, *2*, 855–941.

Jain, Meha, Ram Fishman, Pinki Mondal, Gillian L Galford, Nishan Bhattarai, Shahid Naeem, Upmanu Lall, Balwinder-Singh, and Ruth S DeFries, "Groundwater depletion will reduce cropping intensity in India," *Science Advances*, 2021, *7* (9), eabd2849.

Jayachandran, Seema, "Social norms as a barrier to women's employment in developing countries," *IMF Economic Review*, 2021, *69* (3), 576–595.

Lakshmanan, TR, "Infrastructure and economic transformation," *Advances in Spatial Theory and Dynamics, Amsterdam, North Holland*, 1989, pp. 241–261.

Lee, Kenneth, Edward Miguel, and Catherine Wolfram, "Does household electrification supercharge economic development?," *Journal of Economic Perspectives*, 2020, *34* (1), 122–144.

Lewis, David and Robin Bloch, "SDIs: Infrastructure, agglomeration and the region in industrial policy," *Development Southern Africa*, 1998, *15* (5), 727–755.

Lewis, W Arthur, "Economic Development with Unlimited Supplies of Labour," *The Manchester School*, 1954, *22* (2), 139–191.

Lim, Sunghun, "Global agricultural value chains and structural transformation," Technical Report, National Bureau of Economic Research 2021.

Marshall, Fiona, Mike Ashmore, Fiona Hinchcliffe et al., *A hidden threat to food production: Air pollution and agriculture in the developing world*, International Institute for Environment and Development., 1997.

McCann, Philip and Daniel Shefer, "Location, agglomeration and infrastructure," *Fifty Years of Regional Science*, 2004, pp. 177–196.

Mears, C, T Lee, L Ricciardulli, X Wang, and F Wentz, "RSS Cross-Calibrated Multi-Platform (CCMP) 6-hourly ocean vector wind analysis on 0.25 deg grid, Version 3.0," *Remote Sensing Systems, Santa Rosa, CA, available at https://www. remss. com/, https://doi. org/10.56236/RSS-uv6h30 (last access: 15 January 2024)*, 2022.

Mendelsohn, Robert, "An economic analysis of air pollution from coal-fired power plants," *Journal of Environmental Economics and Management*, 1980, *7* (1), 30–43.

Merfeld, Joshua D, "Moving Up or Just Surviving? Nonfarm Self-Employment in India," *American Journal of Agricultural Economics*, 2020, *102* (1), 32–53.

_ , "Sectoral wage gaps and gender in rural India," *American Journal of Agricultural Economics*, 2023, *105* (2), 434–452.

Michaels, Guy, Ferdinand Rauch, and Stephen J Redding, "Urbanization and structural transformation," *The Quarterly Journal of Economics*, 2012, *127* (2), 535–586.

Moneke, Niclas, "Infrastructure and structural transformation: evidence from ethiopia." PhD dissertation, London School of Economics and Political Science 2020.

Nguyen, Anh and Sunghun Lim, "Structural Transformation in the Era of Trade Protectionism," *Available at SSRN 4426955*, 2023.

Oberschelp, Christopher, Stephan Pfister, CE Raptis, and Stefanie Hellweg, "Global emission hotspots of coal power generation," *Nature Sustainability*, 2019, *2* (2), 113–121.

Peng, Wei, Fabian Wagner, MV Ramana, Haibo Zhai, Mitchell J Small, Carole Dalin, Xin Zhang, and Denise L Mauzerall, "Managing China's coal power plants to address multiple environmental objectives," *Nature Sustainability*, 2018, *1* (11), 693–701.

Perez-Sebastian, Fidel and Jevgenijs Steinbuks, "Public infrastructure and structural transformation," *World Bank Policy Research Working Paper*, 2017, (8285).

Porter, Michael E, "Location, competition, and economic development: Local clusters in a global economy," *Economic development quarterly*, 2000, *14* (1), 15–34.

Poschke, Markus, "The firm size distribution across countries and skill-biased change in entrepreneurial technology," *American Economic Journal: Macroeconomics*, 2018, *10* (3), 1–41.

Raifu, Isiaka Akande, Obianuju Ogochukwu Nnadozie, and Oluwatosin Ademola Adeniyi, "Infrastructure-structural transformation nexus in Africa: the role of financial sector development," *Journal of African Development*, 2021, *22* (1), 124–165.

Ramanathan, Veerabhadran and Gregory Carmichael, "Global and regional climate changes due to black carbon," *Nature geoscience*, 2008, *1* (4), 221–227.

Reddy, V Ratna and Bhagirath Behera, "Impact of water pollution on rural communities: An economic analysis," *Ecological economics*, 2006, *58* (3), 520–537.

Roth, Jonathan, Pedro HC Sant'Anna, Alyssa Bilinski, and John Poe, "What's trending in difference-in-differences? A synthesis of the recent econometrics literature," *Journal of Econometrics*, 2023.

Rud, Juan Pablo, "Infrastructure regulation and reallocations within industry: Theory and evidence from Indian firms," *Journal of Development Economics*, 2012, *99* (1), 116–127.

Samaniego, Roberto M and Juliana Y Sun, "Productivity growth and structural transformation," *Review of Economic Dynamics*, 2016, *21*, 266–285.

Sedai, Ashish Kumar, Ramaa Vasudevan, Anita Alves Pena, and Ray Miller, "Does reliable electrification reduce gender differences? Evidence from India," *Journal of Economic Behavior & Organization*, 2021, *185*, 580–601.

Shahbaz, Muhammad, Muhammad Zakaria, Syed Jawad Hussain Shahzad, and Mantu Kumar Mahalik, "The energy consumption and economic growth nexus in top ten energy-consuming countries: Fresh evidence from using the quantile-on-quantile approach," *Energy Economics*, 2018, *71*, 282–301.

Stern, David I, "Energy and economic growth in the USA: a multivariate approach," *Energy economics*, 1993, *15* (2), 137–150.

_ , "The role of energy in economic growth," *Annals of the New York Academy of Sciences*, 2011, *1219* (1), 26–51.

_ , "Energy and economic growth," in "Routledge handbook of Energy economics," Routledge, 2019, pp. 28–46.

Teignier, Marc, "The role of trade in structural transformation," *Journal of Development Economics*, 2018, *130*, 45–65.

Timilsina, Govinda R, Gal Hochman, and Ze Song, "Infrastructure, economic growth, and poverty: A review," *World Bank Policy Research Working Paper*, 2020, (9258).

Wan, Guanghua and Yan Zhang, "The direct and indirect effects of infrastructure on firm productivity: Evidence from Chinese manufacturing," *China Economic Review*, 2018, *49*, 143–153.

Appendix

Table A1: Summary statistics by year (population census)

	1991	2001	2011
Coal plant	0.17	0.203	0.289
Log population	6.375	6.548	6.702
Emp. rate	0.524	0.535	0.52
Ag. rate	0.755	0.545	0.496
Log agriculture	5.129	4.937	4.918
HH manuf. rate	0.016	0.021	0.017
Literacy rate	0.324	0.467	0.574

Note: Values are means for each year in the population census. Coal plant is a dummy equal to one if a village is within 50km of an operating coal plant.

Table A2: Summary statistics by year (economic census)

	1990	1998	2005	2013
Coal plant	0.169	0.190	0.202	0.312
Employment rate	0.044	0.064	0.061	0.069
Manufacturing rate	0.301	0.240	0.216	0.167
Services rate	0.682	0.740	0.763	0.806
Large firms rate	0.030	0.032	0.028	0.030

Note: Values are means for each year in the economic census. Coal plant is a dummy equal to one if a village is within 50km of an operating coal plant.

Table A3: Coal plants and firm counts

	All	Size <21	Size 21+
Coal plant within 50km	-1.211*	-1.244*	4.068***
	(0.668)	(0.661)	(1.523)
Untreated mean	44.014	43.791	0.223
Observations	1,604,998	1,604,998	1,604,600

Note: Results use the did2s package in R, which includes village and wave fixed effects. Standard errors are in parentheses and clustered at the village level. The data are from the economic census. The first column is the number of firms in the village. The second column is number of firms with less than 21 employees. The third column is the number of firms with 21 or more. * $p<0.10$ ** $p<0.05$ *** $p<0.01$

Table A4: Coal plants and employment in firms by gender, economic census

	Male	Female
Coal plant within 50km	0.066***	0.036***
	(0.006)	(0.004)
Untreated mean	0.088	0.032
Observations	1,522,706	1,522,381

Note: Results use the did2s package in R, which includes village and wave fixed effects. Standard errors are in parentheses and clustered at the village level. The data are from the economic census and does not include agricultural firms or household firms. The first column is the employment rate for men and the second column is the employment rate for women. * p<0.10 ** p<0.05 *** p<0.01

Table A5: Coal plants and employment by gender, population census

	Emp. rate (male)	Emp. rate (female)
Coal plant within 50km	-0.002***	-0.001
	(0.001)	(0.001)
Untreated mean	0.644	0.412
Observations	1,433,954	1,433,086

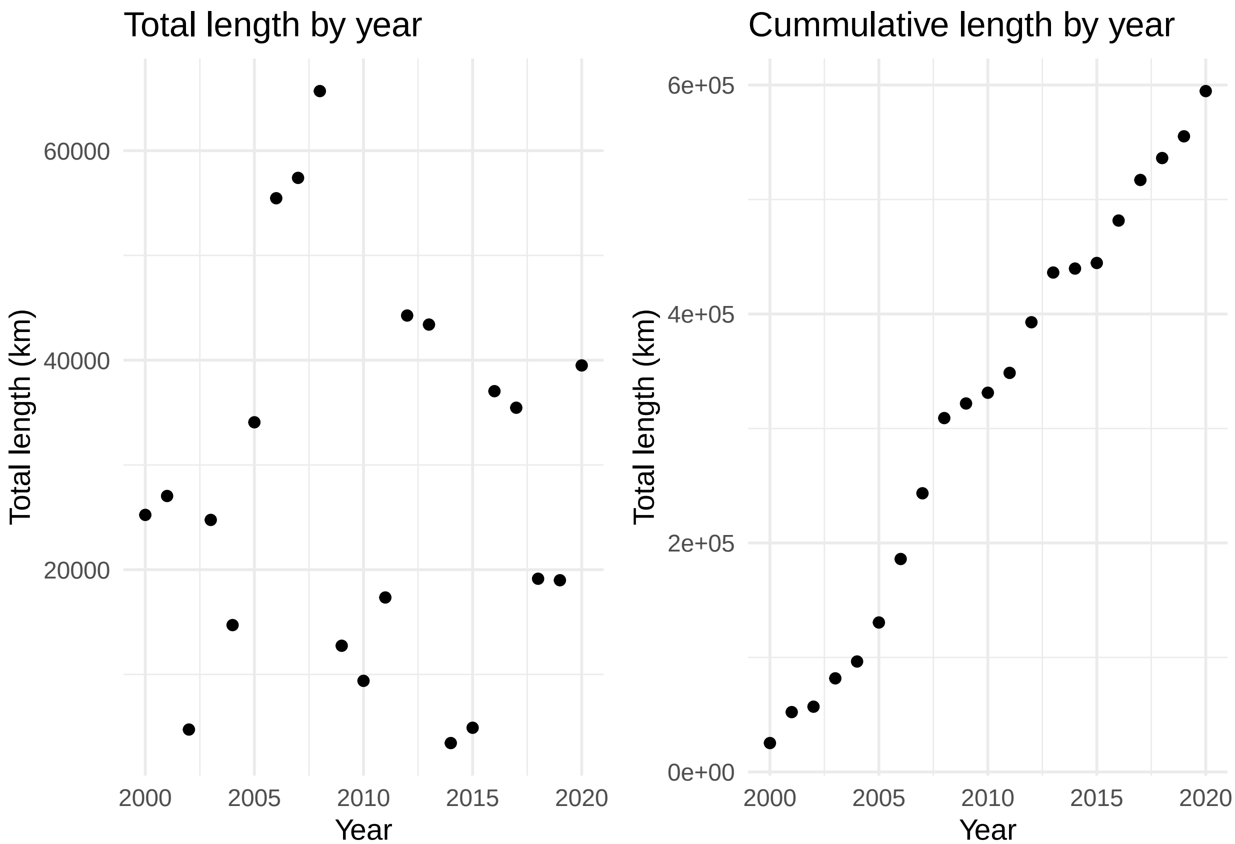
Note: Results use the did2s package in R, which includes village and wave fixed effects. The data are from the population census. Standard errors are in parentheses and clustered at the village level. The first column is the proportion of men over seven years of age who are employed. The second column is the proportion of women over seven years of age who are employed. * p<0.10 ** p<0.05 *** p<0.01

Table A6: Coal plants, pollution exposure, and firm counts

	All	Size <20	Size 21+
Top quartile of exposure	-	-	2.240
	2.248***	2.241***	
	(0.698)	(0.695)	(2.107)
Untreated mean	49.067	48.803	0.35
Observations	505,278	505,278	505,278

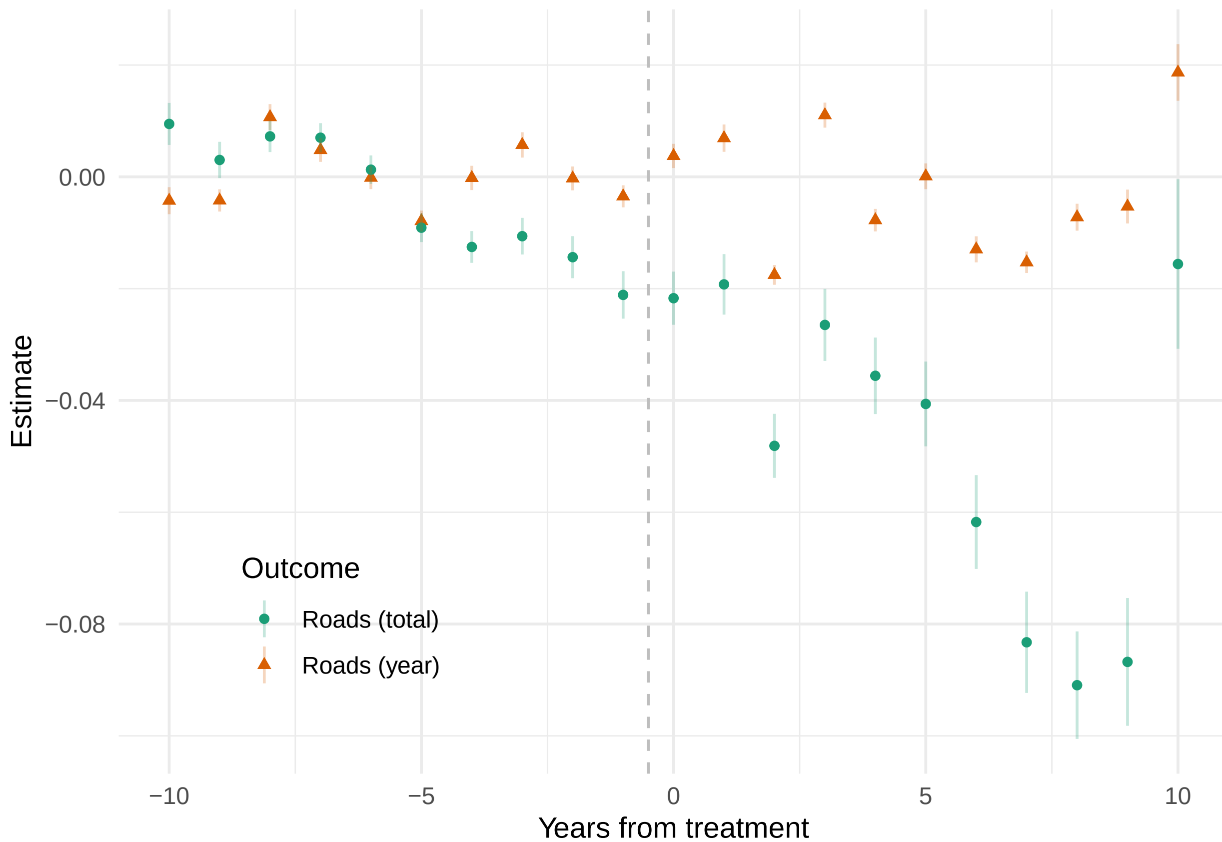
Note: Results use the did2s package in R, which includes village and wave fixed effects. Standard errors are in parentheses and clustered at the village level. The data are from the economic census. The first column is the number of firms in the village. The second column is number of firms with less than 21 employees. The third column is the number of firms with 21 or more. * p<0.10 ** p<0.05 *** p<0.01

Figure A1: Roads built through PMGSY



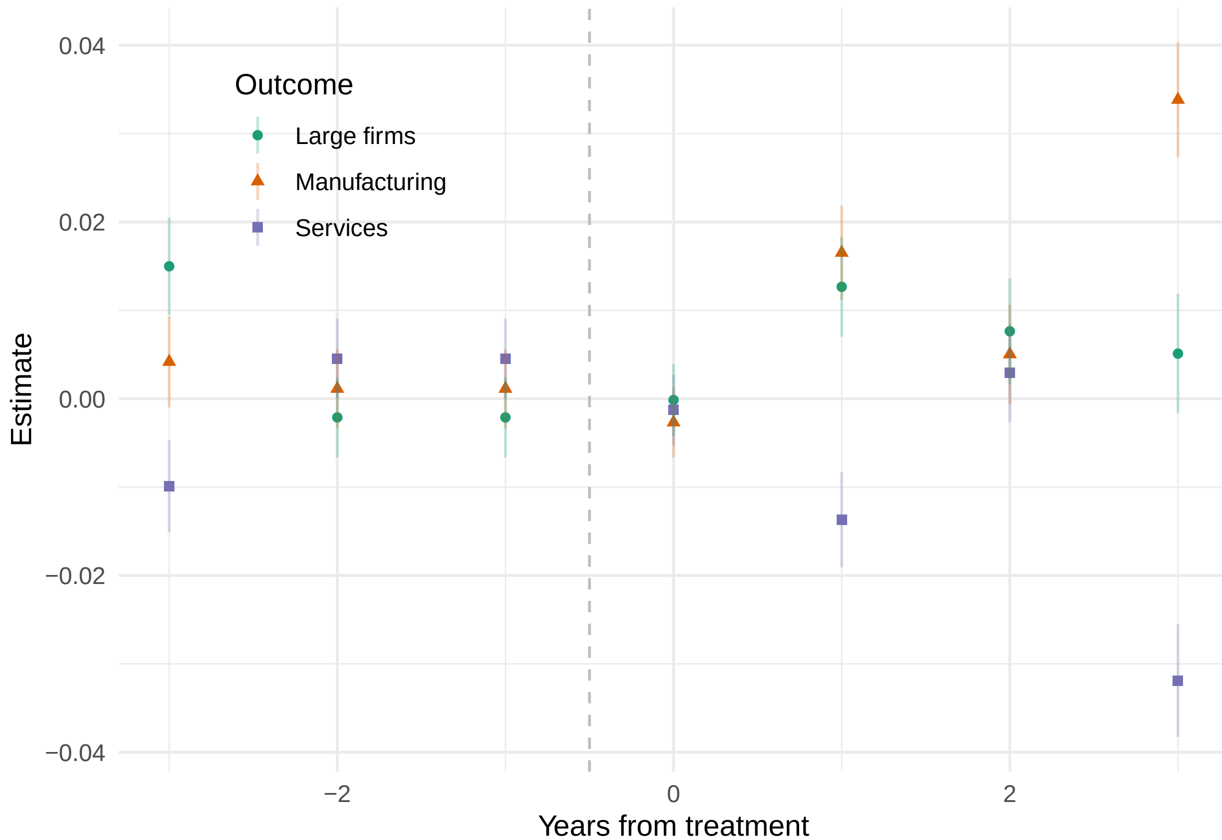
Note: The plots show the total length of roads built through the PMGSY program. The left figure shows the total built in each year while the right figure shows the cummulative length built up to a given year.

Figure A2: Event study of PMGSY roads



Note: Event study results are calculated using the did2s function in R. Time to treatment is based on the year a coal plant opened.

Figure A3: Event study by exposure (economic census)



Note: Event study results are calculated using the did2s function in R. The coefficients compare villages located in the top quartile of wind direction from the location of the coal plant. Time to treatment is based on waves of the economic census.