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IMPACTS OF THE CLEAN AIR ACT ON THE POWER SECTOR FROM  
1938-1994: ANTICIPATION AND ADAPTATION

Karen Clay  
Akshaya Jha  
Joshua A. Lewis  
Edson R. Severnini

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Impacts of the Clean Air Act on the Power Sector from 1938-1994: Anticipation and Adaptation  
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### **ABSTRACT**

The passage of landmark government regulation is often the culmination of evolving social pressure and incremental policy change. During this process, firms may preemptively adjust behavior in anticipation of impending regulation, making it difficult to quantify the overall economic impact of the legislation. This study leverages newly digitized data on the operation of virtually every fossil-fuel power plant in the United States from 1938-1994 to examine the impacts of the 1970 Clean Air Act (CAA) on the power sector. This unique long panel provides an extended pre-regulation benchmark, allowing us to account for both anticipatory behavior by electric utilities in the years leading up to the Act's passage and reallocation effects of the CAA across plant vintages. We find that the CAA led to large and persistent decreases in output and productivity, but only for plants that opened before 1963. This timing aligns with the passage of the original 1963 CAA, which provided the federal government with limited authority to "control" air pollution, but signaled impending federal regulation. We provide historical evidence of anticipatory responses by utilities in the design and siting of plants that opened after 1963. We also find that the aggregate productivity losses of the CAA borne by the power sector were substantially mitigated by the reallocation of output from older less efficient power plants to newer plants.

Karen Clay  
Heinz College  
Carnegie Mellon University  
5000 Forbes Avenue  
Pittsburgh, PA 15213  
and NBER  
kclay@andrew.cmu.edu

Akshaya Jha  
Carnegie Mellon University  
Hamburg Hall Office 2218  
4800 Forbes Avenue  
Pittsburgh, PA 15232  
Website: <http://www.akshayajha.com>  
akshayaj@andrew.cmu.edu

Joshua A. Lewis  
University of Montreal  
Département de sciences économiques  
3150 rue Jean-Brillant  
Montréal, QC, H3T 1N8  
joshua.lewis@umontreal.ca

Edson R. Severnini  
H. John Heinz III College  
Carnegie Mellon University  
4800 Forbes Ave #2114B  
Pittsburgh, PA 15213  
and NBER  
ersevernini@gmail.com

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# 1 Introduction

Government regulation permeates all aspects of the modern economy. It affects a range of outcomes from worker safety to air quality to the provision of housing and medical care. Landmark policies, such as the Housing Act of 1949, Medicare and Medicaid in 1965, and the Clean Air Act of 1970, have fundamentally altered major sectors of the economy. Although transformative, these policies are often the culmination of evolving social pressure and incremental policy change.<sup>1</sup> During this lengthy process, economic agents may update their expectations over the likelihood of future regulation and take anticipatory actions to facilitate the transition to a post-regulatory regime.

Anticipatory behavior makes it difficult to empirically estimate the full effects of landmark regulations, since outcomes in the years leading up to enactment may not provide a valid benchmark against which post-regulation outcomes can be compared. Moreover, differences in producers' abilities to preemptively respond can have important distributional consequences with potentially first order impacts on aggregate outcomes.

This paper studies the impacts of the 1970 Clean Air Act (CAA) on the power sector. The CAA is the centerpiece of local air pollution regulation in the United States and a model for environmental policy around the world. It constitutes a prime example of landmark regulation that emerged after an extended period of incremental policy change. During this process, polluting plants may have preemptively adjusted behavior, since the Act's passage was largely foreseeable in the years leading up to its enactment.<sup>2</sup>

We leverage newly digitized data on the operation of virtually every fossil-fuel power plant in the United States from 1938-1994 to examine the impacts of the 1970 CAA on electricity producers. This setting provides an exceptional opportunity to account for both *anticipatory behavior* by electric utilities in the years preceding the Act's passage, and reallocative effects of the CAA across older and newer plants. The long time horizon allows us to establish a pre-regulatory benchmark, and estimate effects of the CAA across

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<sup>1</sup>The Housing Act of 1949 was passed 15 years after the creation of the Federal Housing Administration, Medicare and Medicaid were signed into law 20 years after being proposed by President Truman, and the 1970 Clean Air Act was passed 22 years after the deadly Donora Smog of 1948.

<sup>2</sup>However, the precise timing and regulatory details of the 1970 CAA were largely unexpected (see Section 2). For example, there was a large and abrupt change in public opinion in favor of environmental protection around 1970. In May 1969, only one percent of the population included "pollution/ecology" as one the most important domestic problems in the United States. In May 1971, 25 percent did so, and that category was second only to "inflation/cost of living/taxes" (ACIR, 1981, p.19).

plant vintages that were more or less able to preemptively mitigate the consequences of the regulation. Because power plants are immobile and have extended lifespans, there is little concern regarding the relocation or exit of firms as is often the case in long-run analyses.<sup>3</sup> Detailed data on plant operations allow us to estimate annual plant-level “pollution-unadjusted” total factor productivity (PU-TFP).<sup>4</sup> We use these measures to estimate the direct effects of the CAA on plant productivity and assess the indirect productivity effects driven by the reallocation of output across older versus newer plants.<sup>5</sup>

Our empirical approach utilizes the geographic and temporal variation in environmental regulation built into the CAA, which designated counties to be either in attainment or nonattainment based on standards set forth by the National Ambient Air Quality Standards (NAAQS).<sup>6</sup> Whereas producers in attainment counties were subject to limited regulation, power plants located in nonattainment counties were forced by state and local regulators to take potentially costly actions to reduce pollution levels. Pollution emissions reductions were typically achieved by decreasing output, switching to “cleaner” fuels, or installing pollution abatement technology. We adopt a difference-in-differences strategy that compares the changes in outcomes of plants located in counties in versus out of attainment, before and after enforcement went into place. Event study graphs that motivate the regression analyses support the parallel trends assumption.

We find that county nonattainment designations under the CAA had negative effects on output and productivity, but only for plants built before 1963.<sup>7</sup> The productivity losses incurred by pre-1963 plants are economically large and persistent, suggesting that

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<sup>3</sup>The typical lifespan of a fossil-fuel power plant was 40 years in our period of analysis. Rate-of-return regulation in the industry limited the incentive to relocate operations and ensured that monopoly producers faced virtually no risk of bankruptcy.

<sup>4</sup>Our measure focuses on the productivity losses incurred by plants ignoring the external costs of pollution borne by society at large. We estimate PU-TFP using the method specified by Akerberg, Caves and Frazer (2015). Importantly, the estimation does not require the use of balance sheet data, which could be biased due to changes in market power in output and input markets. See, for example, Foster, Haltiwanger and Syverson (2008), Hsieh and Klenow (2009), and De Loecker (2011) for discussions of the advantages of productivity estimation based on input and output quantities (TFP-Q) rather than revenue and input costs (TFP-R).

<sup>5</sup>When markets are efficient, reallocation effects will not impact aggregate productivity (Solow, 1957). However, in the power sector, there were large productivity differences by power plant vintage, consistent with electric utilities operating as local monopolies during our sample period. As a result, distributional effects of regulation may have first order impacts on aggregate outcomes.

<sup>6</sup>The NAAQS initially covered five different criteria pollutants: carbon monoxide, particulate matter, nitrogen dioxide, ozone, and sulfur dioxide. Annual county-level nonattainment designations were based on whether air pollution concentrations exceeded the federal standard for the criteria pollutant.

<sup>7</sup>These plants responded to nonattainment status primarily by decreasing output and substituting towards higher cost low-sulfur coal.

these plants were unable to adapt to environmental regulation even in the long run. In contrast, the effects of the CAA on plants that opened from 1963 to 1971 are small and statistically insignificant. The timing of these patterns aligns with the passage of the original 1963 CAA, which provided the federal government with the authority to “control” air pollution, signalling impending environmental regulations. Plants that opened after this key year were largely unaffected by subsequent regulatory requirements.

What explains the absence of productivity effects for plants that opened immediately prior to the passage of the 1970 CAA? Both historical and empirical evidence suggest that electric utilities were able to take anticipatory actions to mitigate the effects of nonattainment status in the post-1972 period for their plants built between 1963 and 1971. Historical sources document preemptive design changes after 1963, including increases in plant stack height and the use of pollution abatement technology. We document a sharp increase in patenting related to power systems between 1963-1971. We also find a post-1963 shift in siting plants away from counties with pollution monitors. Taken together, both the historical narrative and descriptive evidence point to anticipation playing a key role in the eventual costs of complying with the CAA.

The aggregate productivity effects of the CAA were substantially mitigated by the reallocation of output away from older, less productive power plants. We estimate that the declines in output from plants built before 1963 in nonattainment counties were largely offset by increased output from new fossil fuel plants that opened in the post-1972 period. Since these plants have substantially higher average PU-TFP levels, the reallocative response of the CAA led to an increase in aggregate productivity. A simple calculation that accounts for this regulatory-induced shift in production across plants implies that the CAA imposed annual productivity losses of \$3.5 billion (2020 dollars) in the power sector. Notably, we estimate that roughly half of the aggregate long-run losses were offset by the reallocation of production across plants.

Lastly, we show that an extended pre-regulatory period is crucial to capturing the full impacts of the 1970 CAA. We find that the magnitude of the nonattainment effects decline as we artificially increase the earliest year included in the sample – for example, estimating on 1940-1997 versus 1950-1997. The estimated effects are insignificant for samples that begin after 1965. Moreover, we find that the estimated effects were driven by the initial 1972 attainment designations and that post-1972 changes in attainment status

had small and statistically insignificant effects on plant output and PU-TFP. Similarly, decompositions based on Goodman-Bacon (2018) show that the empirical identification of our primary nonattainment effects comes from the initial 1972 county nonattainment designations. These patterns are consistent with anticipatory responses to environmental regulation, since post-1972 changes in attainment status were largely determined by known trends in county-level pollution.

This paper makes three main contributions to the literature. First, it provides the first causal estimates of the impacts of the 1970 Clean Air Act (CAA) that account for anticipatory behavior. Our findings support Malani and Reif (2015)’s analysis demonstrating the potential for anticipatory behavior to substantially alter policy impact estimates. In a related context, Keiser and Shapiro (2019*a,b*) also document that water pollution declined more rapidly before the passage of the landmark 1972 Clean Water Act than after it. Because federal legislation pertaining to water pollution control was also enacted prior to 1972, anticipatory behavior may have played a role in that setting as well.<sup>8</sup>

Second, our findings indicate that distributional impacts of regulation can attenuate first order effects on aggregate outcomes through reallocative responses (e.g., Kline and Moretti, 2014; Hornbeck and Rotemberg, 2019). In the context of the CAA, the within-firm efficiency costs borne by older producers were substantially mitigated by reallocative efficiency gains, as output was directed towards more productive plants. These results also suggest that the potential external costs of delayed plant upgrade and/or exit under the CAA’s grandfathering provisions (e.g., List, Millimet and McHone, 2004; Stavins, 2006) may have been alleviated by reallocative responses across producers.

The third contribution regards the critical importance of a long time horizon to assess the effects of transformative changes, especially when they involve nearly irreversible investments such as large power plants (e.g., Bleakley and Lin, 2012; Hornbeck, 2012; Hornbeck and Keniston, 2017). There is an extensive literature documenting the impacts of the CAA on firm behavior (see reviews by Currie and Walker, 2019; Aldy et al., Forthcoming),<sup>9</sup> but most of the prior studies have relied on post-1972 variation in attainment

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<sup>8</sup>Indeed, a 1981 report from the U.S. Advisory Commission on Intergovernmental Relations (ACIR) states that “[t]he history of federal water pollution control initiatives from 1948 to 1966 is a vivid example of government action through incremental changes. (...) [F]ederal spending (...) increased from a small loan program funded at about \$1 million per year to a grant-in-aid outlay of \$3.55 billion over five years. In the same period, Congress moved from a posture of denying federal authorities any enforcement powers to requiring the enactment of national water quality standards” (ACIR, 1981, p.12).

<sup>9</sup>For impacts on manufacturing, see, for example, Henderson (1996); Becker and Henderson (2000);

status, and none have included data from before 1963. We show that an extended pre-treatment period is crucial for estimating the full economic impact of the CAA, because of the anticipatory adjustments made in the years leading up to the Act’s passage.

The remainder of the paper is organized as follows. Section 2 presents background information on how the Clean Air Act might have affected the electricity industry. Section 3 outlines our conceptual framework for how plants choose inputs and output with versus without the Clean Air Act. Section 4 describes the data sources and summary statistics, and introduces our difference-in-differences approach to estimate the effect of nonattainment with NAAQS on plant outcomes. Section 5 reports and discusses the main findings, along with robustness checks and further heterogeneity analyses. Section 6 presents back-of-the-envelope calculations on the nationwide effects of the 1970 CAA on PU-TFP in the power sector. Lastly, Section 7 concludes.

## 2 Background

This section describes three phases of air pollution regulation in the United States. The first phase was up to 1962, when most of the federal efforts were directed towards data collection. The second phase was 1963-1971, when it was clear that further regulation was coming. The 1963 legislation gave the federal government the ability to intervene in specific settings. By 1965, the federal government had started to take enforcement actions – called conference proceedings – against the worst polluters and groups of polluters where interstate pollution was an issue. The third phase was from 1972 onward when the 1970 CAA legislation took effect. Subsequent amendments in 1977 and 1990 further strengthened the national pollution control regulatory framework.

### 2.1 Up to 1962

The modern clean-air movement arose in the postwar period following a number of high profile incidents of extreme air pollution, notably the 1948 Donora smog and the 1952

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Greenstone (2002); Gray and Shadbegian (2003); Greenstone, List and Syverson (2012); Ryan (2012); Kahn and Mansur (2013); Curtis (2018). For impacts on the power sector, see, for example, Gollop and Roberts (1983, 1985); Nelson, Tietenberg and Donihue (1993); Carlson et al. (2000); Ferris, Shadbegian and Wolverton (2014); Sheriff, Ferris and Shadbegian (2019).

London smog (Clay, 2018). These events received international publicity, raised public awareness about the relationship between air quality and health, and created the impetus for federal action.<sup>10</sup>

Federal legislation under the 1955 Air Pollution Control Act provided funding for research and technical assistance related to air pollution control. One outcome of this legislation was the creation of air pollution monitoring network. Although initially small, by 1962 the network included 270 monitors in 205 counties. The 1955 Act authorized a modest research budget and left the responsibility of prevention and control of air pollution to the states, although by 1960 there were no state air quality standards (Stern, 1982). A report by the U.S. Advisory Commission on Intergovernmental Relations offers an assessment of the impact of the 1955 Air Pollution Control Act: “It legislated little and, correspondingly, accomplished little” (ACIR, 1981, p.12).

## **2.2 1963-1971**

The Clean Air Act of 1963 (1963 CAA) signalled an important shift in the role of the federal government in combating air pollution. This was the first federal legislation that gave the federal government the authority to “control” air pollution. The 1963 CAA included a conference procedure in section 115. In 1965, the Federal government held the first two abatement conferences involving interstate polluters, a pulp mill and a rendering plant (EPA, 1973). A total of 11 abatement conferences would be held through 1971.<sup>11</sup> The 1965 Amendment to the 1963 CAA addressed motor vehicles, the 1967 Air Quality Act strengthened federal enforcement powers. By 1966, ten states had set ambient air quality standards (Stern, 1982).<sup>12</sup>

A number of pieces of evidence suggest that electric utilities altered behavior after 1963 in anticipation of further regulation. The 1966 “Steam-Electric Plant Construction Cost and Annual Production Expenses” report dedicates, for the first time, a section on “environmental influences on plant design, construction, and operation.” It points out that among other factors, air pollution was “emerging as major social-economic issues

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<sup>10</sup>Around the same time, severe ongoing smog problems in Los Angeles led California’s state officials to begin lobbying for federal legislation.

<sup>11</sup>Interestingly, these procedures were not new. Similar procedures were included in the 1956 Federal Water Pollution Control Act and had been used beginning in 1957 (EPA, 1973).

<sup>12</sup>In the empirical analysis, we assess the role of these state-level standards on power plant outcomes.

affecting the electric power industry” (FPC, 1967, p.ix).<sup>13</sup> The 1968 reports adds that “[u]tilities are giving increasing attention to the location and design of new plants and to lessening the impact of these facilities on the environment. (...) Most new coal and oil fired plants include high efficiency electrostatic precipitators to remove particulate matter from stack discharges. (...) High stacks are frequently used to obtain greater dispersion and reduce ground level concentration of oxides of sulfur, and greater attention is being given the selection of coal and oil fuels of lower sulfur content” (FPC, 1969, p.ix). The 1970 reports finally states that “[e]nvironmental factors are now a major, and often dominant, consideration in the siting and design of new steam-electric generating facilities. (...) All coal-fired units will employ electrostatic precipitators, wet scrubbers, or other efficient methods for controlling particulate emissions and many will be designed for later application of stack systems for removal of sulfur oxides which are now under development” (FPC, 1972, p.x).

The characteristics of power plants that opened in the post-1963 period are consistent with anticipatory behavior by electric utilities. Appendix Figure A.1 shows an increase in average smokestack height in the late 1960s that does not align with the more gradual increase in generator size. Appendix Figure A.2 shows that installation of flue gas particulate (FGP) collectors was already common before 1970. Finally, Appendix Figure A.3 shows a sharp increase in the number of patents granted for power systems in the mid- and late-1960s. These patterns may reflect the increased incentive for technological change in response to anticipated regulatory requirements following the passage of the 1963 CAA.<sup>14</sup>

Appendix Table A.1 shows a change in the siting of plants that opened between 1963 and 1971 that is consistent with preemptive avoidance behavior by electric utilities. In comparison to pre-1963 plants, newer plants were systematically less likely to be located in a county with an air pollution monitor. Interestingly, we find no pre-1972 differences in the probability of siting plants in future nonattainment counties, suggesting that the regulatory details of the CAA regarding which counties would ultimately be targeted

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<sup>13</sup>The report also states that “[t]echnology for the removal of particulate matter has been available for some time; however, the demand for very high efficiency (99 percent+) electrostatic precipitators is growing rapidly. Commercial devices for the removal of oxides of sulfur from the flue gases are not yet available (...) In the meantime, (...) higher boiler stacks are being installed to attain greater dispersion” (FPC, 1967, pp. ix-x).

<sup>14</sup>Unfortunately, the aggregate data do not permit a finer decomposition of the sources of these new patents.

were largely unexpected.

These preemptive changes by electric utilities may partly account for the increase in construction costs of coal plants around 1966 (see Appendix Figure A.4). In a discussion of these trends, Joskow and Rose (1985) state that they “expected to see the major increases appear later as a result of new plants’ coming on line with state-of-the-art environmental control equipment in response to regulations introduced in the 1970s; but costs clearly begin to increase by the late 1960s” (p. 21). The rising costs were paid for by rate increases, which were approved in public utility commission hearings.<sup>15</sup>

## 2.3 1972 onward

The 1970 Clean Air Act (CAA) marked the first federal effort to regulate air quality on a large scale. The U.S. EPA was established and directed to set National Ambient Air Quality Standards (NAAQS) for certain criteria air pollutants: total suspended particles (*TSP*) or particulate matter (*PM*), carbon monoxide (*CO*), sulfur dioxide (*SO*<sub>2</sub>), nitrogen dioxide (*NO*<sub>2</sub>), and ozone (*O*<sub>3</sub>). Lead was later added as a criteria pollutant and standards were established for other pollutants. Beginning in 1972, each county received an annual designation of nonattainment or attainment for each of the criteria pollutants.<sup>16</sup> This designation was dependant on whether air concentrations exceeded the federally mandated standards.

Each state was required to submit a state implementation plan (SIP) outlining how any noncompliant regions would be brought into compliance with the NAAQS. Typically states totaled up estimated stationary source emissions in each nonattainment area, divided it by an estimate of total emissions needed to achieve attainment status, and ordered plants to reduce emissions by that ratio (Roberts and Farrell, 1978). All states, territories, and the District of Columbia submitted SIPs by the end of 1972 (EPA, 1973).<sup>17</sup>

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<sup>15</sup>Between 1963-1968 operating costs generally decreased and rates of return were higher than in the recent past. In line with this, there were between two and five cases a year. By 1969, inflation, increases in fossil fuel prices, and environmental factors had begun to drive up cost. The number of cases rose from 16 in 1969 to 53 in 1972. Environmental groups began to be active in rate cases as well.

<sup>16</sup>The *Code of Federal Regulations* (CFR) started to publish a list of nonattainment counties only in 1978. Following Greenstone (2002), we consider a county nonattainment for a pollutant over the period 1972-1977 if it had a pollution monitor reading that exceeded the relevant federal standard in 1972.

<sup>17</sup>The documentary record on SIPs is complicated by the fact that parts of SIPs were frequently being modified or litigated. Still, the EPA was able to write in late 1974 that “[w]ith a few notable exceptions

Thus, existing power plants in nonattainment counties faced greater constraints on emissions than plants in attainment counties. To achieve emissions targets, plants could reduce annual net generation or burn more expensive, lower sulfur coal. Alternatively, they could install flue gas desulfurization (FGD) systems – colloquially known as “scrubbers.” Nevertheless, these installations were costly and the risk of subjecting the plant to New Source Performance Standards (NSPS), which required that any substantial investments or modifications to existing plants be accompanied by installation of pollution abatement equipment.<sup>18</sup> Despite these concerns, scrubber installations increased after 1970 (see Appendix Figures A.2 and A.5).

Environmental regulation under the 1970 CAA led to a sharp drop in emissions by power plants. By 1975, the EPA reported that 261 of the 394 coal-fired power plants were in compliance with SIP emission limitations or abatement schedules. Consistent with this, the EPA found that TSP and  $\text{SO}_x$  emissions at coal-fired steam electric power plants had fallen (EPA, 1976*b*). TSP emissions fell from 4.2 million tons in 1970 to 2.9 million tons in 1974, and  $\text{SO}_x$  emissions fell from 15.4 million tons to 13.6 million tons.<sup>19</sup>

Measures of total suspended particulates (TSP) fell at monitors in counties that would ever be in nonattainment after 1972. Appendix Figure A.6 plots the estimated coefficients of a regression of TSP on year fixed effects interacted with attainment status, controlling for pollution monitor fixed effects.<sup>20</sup> Both nonattainment and attainment had declines in measured TSP over time, although the absolute reductions were larger in nonattainment counties. It is notable that these downward trends preceded the passage of the 1970 CAA.

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(e.g. sulfur oxide emission limitations in the State of Ohio) all States now have fully enforceable emission limits affecting stationary sources” (EPA, 1975, p.12).

<sup>18</sup>In nonattainment counties, these abatement technologies had to meet the “lowest achievable emissions rate” regardless of costs, whereas in attainment counties, plants were required to install the “best available control technologies” with consideration over the costs. The 1977 amendments required the use of scrubbers for coal-fired plants built after 1978.

<sup>19</sup>Of the 133 plants not in compliance, 102 were located in Ohio (47), Indiana (29), and Illinois (26). In these states, there had been significant delay and litigation around  $\text{SO}_x$  control plans (EPA, 1976*a*). Of remaining 31 plants not in compliance, ten were part of the Tennessee Valley Authority and were the subject of a consent decree (see Appendix Table A.2); SIP revisions were underway for 7 plants; and the remaining plants were in litigation or otherwise subject to EPA action.

<sup>20</sup>Some caution should be taken in interpreting these trends, given the expansion of the monitoring network over the time period.

### 3 Conceptual Framework

This section provides a conceptual framework for understanding the margins of adjustment to the Clean Air Act for plants built prior to 1963, between 1963-1971, from 1972 onward. We relegate the full mathematical formulation corresponding to this framework to Appendix B. This appendix section and Appendix C.2 also describes how we measure annual plant-level total factor productivity.

In this conceptual framework, each plant  $i$  produces electricity output  $O_{it}$  in each year  $t$  using the following three inputs: capacity  $K_{it}$ , labor  $L_{it}$ , and input heat energy  $E_{it}$ . Generating capacity takes a longer time to adjust than either labor or energy while labor takes a longer time to adjust than energy. Indeed, we think of energy as a perfect complement to the other inputs: holding energy fixed, output cannot be increased by increasing either labor or capital.

Pollution  $P_{it}$  is also emitted as a consequence of burning fossil fuels in order to produce output  $O_{it}$ . Plants can reduce emissions by decreasing output, burning cleaner fuel such as coal with lower sulfur content, or installing pollution abatement technology (see, for example, Appendix Table A.2). Each of these actions come with environmental benefits for the public and costs for power plants. This paper focuses solely on the costs incurred by power plants. For example, consider a plant that reduces output in response to environmental regulations. It is unable to reduce its capacity, and it may not be able to decrease its number of employees because of fixed staffing requirements. This plant produces less output for the same level of inputs; *pollution-unadjusted* total factor productivity (PU-TFP) thus falls as a consequence of the environmental regulation. We emphasize pollution-unadjusted because the environmental benefits associated with reduced output (and thus decreased pollution emissions) are not captured in our quantification of annual plant-level productivity.<sup>21,22</sup>

We hypothesize that plants built up to 1962, from 1963 to 1971, and from 1972 onward will respond differently to the stricter environmental regulations associated with county-level nonattainment. Plants built before 1963 can decrease emissions by reducing output,

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<sup>21</sup>As stated by Currie and Walker (2019), “if a regulation induces firms to use less pollution (that is, fewer unmeasured inputs), then it may look like total factor productivity declines when in fact the ‘true’ regulation-induced productivity change remains elusive” (p.15).

<sup>22</sup>See Muller, Mendelsohn and Nordhaus (2011); Muller (2014, 2019) for measurements of GDP that adjust for pollution damages.

burning cleaner fuel or making modifications to the plant. However, making modifications to the plant such as installing pollution abatement technology is expensive. Further, making “major modifications” can subject plants built prior to 1972 to the stricter set of environmental regulations applied to new plants (i.e.: the “New Source Performance Standards”).<sup>23</sup> Given this combination of incentives, we hypothesize that plants built before 1963 will be unlikely to respond to nonattainment status by installing pollution abatement technology unless this is their last resort. Instead, plants built before 1963 are more likely to decrease emissions by some combination of reducing output and burning cleaner fuels. To the extent that the plant is unable to perfectly adjust their other inputs to match this reduction in output or change in fuel, the plant’s PU-TFP will fall.<sup>24</sup>

In contrast to plants built up to 1962, we expect that plants built starting in 1963 and especially plants starting in 1972 will be much less affected by nonattainment status. Plants built from 1963-1971 that anticipate further environmental regulation can make siting and design decisions to reduce the likelihood of being located in more polluted counties that could be subject to more stringent environmental regulations in the future. All of the plants built after 1972 are subject to the NSPS; plants built after 1978 were required to install scrubbers under the NSPS. It is unlikely that nonattainment forces substantial reductions in pollution emissions from plants built after 1972 because: (1) all of these plants are already subject to the stricter NSPS policy and (2) these plants were sited and designed with full knowledge that the NAAQS were in place.

## 4 Data and Empirical Strategy

### 4.1 Data Description

This paper uses annual plant-level data for the vast majority of fossil fuel fired power plants in the United States for the period 1938-1994.<sup>25</sup> The Federal Power Commission

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<sup>23</sup>That being said, it was only in the late 1990s that the EPA announced sweeping enforcement action against 46 power plants for violations of the New Source Review (NSR) – see Keohane, Mansur and Voynov (2009).

<sup>24</sup>These plants may run longer to compensate for the reduction in output, as reported in Appendix Table A.3.

<sup>25</sup>We end our sample period in 1994 because the market-based components of the Clean Air Act of 1990 were implemented in 1995. Moreover, some U.S. states decided to shift the provision of electricity generation from output price regulation to electricity market mechanisms beginning in 1998 (“electricity

(FPC), later renamed Federal Energy Regulatory Commission (FERC), began publishing detailed plant-level information in 1948.<sup>26</sup> The initial volume included retrospective data beginning in 1938. We digitized the data for 1938-1981, and use similar data collected by FERC for 1982-1994.<sup>27</sup> Further details on the data construction process are provided in Appendix C.

Our primary specifications focus on the impact of nonattainment with the National Ambient Air Quality Standards (NAAQS) on the operations of fossil-fuel-fired power plants. There are about 1,000 fossil-fuel-fired plants in our data, and they are located in approximately 700 U.S. counties, as displayed in Appendix Figure C.2. We differentiate between “existing” plants that were built before 1972 and “new” plants that were built after 1972 because only plants built after 1972 were subject to the New Source Performance Standards. Appendix Table C.1 presents the number of existing and new plants in our data that were always in attainment versus ever in nonattainment between 1972-1994. The table also shows that the share of plants that were in always attainment counties rose from 0.34 before 1963 to 0.40 from 1963-1971 to 0.44 after 1972. Attainment status is persistent: conditional on being in attainment (nonattainment) in year  $t - 1$ , the empirical probability of being in attainment (nonattainment) in year  $t$  is over 0.9 (Appendix Table C.2). The vast majority of temporal variation in nonattainment status stems from the initial impact of the CAA as opposed to post-1972 changes.

We assess how nonattainment impacts a range of annual plant-level outcomes, including electricity output (in MWh), electricity generating capacity (in MW), number of employees, fuel use (in mmBTU), and fuel prices. We also use these data on inputs and output electricity to estimate pollution-unadjusted total factor productivity (PU-TFP). Appendix Table C.3 reports summary statistics over the period 1938-1994.<sup>28</sup> The average plant in our sample has approximately 135 employees, 528 MW in nameplate capacity, and generates roughly 2,300 GWh of electricity each year.

Figure 1 plots annual total electricity generation for three vintages of plants (pre-restructuring”). Market-based plants face both a different set of incentives and a different set of reporting requirements.

<sup>26</sup>Appendix Figure C.1 displays a page of the 1957 report as an example.

<sup>27</sup>Part of the digitization for 1938-1981 was done with resources from the NSF grant SES 1627432. We thank Ron Shadbegian and other researchers at the USEPA for providing the data for 1982-1994.

<sup>28</sup>Details on the estimation of PU-TFP are provided in Appendix B and Appendix C.2. The estimated parameters of the production function are reported in Appendix Table C.4.

1963, 1963-1971, and post-1971) in nonattainment and attainment counties.<sup>29</sup> From this figure, we see that electricity generation from fossil fuel plants grew at a faster rate in ever-nonattainment counties relative to always-attainment counties prior to 1972. After 1972, production from “existing” fossil fuel plants built before 1972 decreased in ever-nonattainment counties but remained stable for existing plants in always-attainment counties. In contrast, we see a precipitous rise in production from new power plants built after 1972 in always-attainment counties along with a slower increase in production from new power plants in ever-nonattainment counties.<sup>30</sup>

Appendix Figure C.4 documents annual total electricity generating capacity over our sample period. This figure shows that coal capacity grew up through 1990. In contrast, oil and natural gas capacity increased up to roughly 1980 before declining from 1980-1994. This trend is due in large part to Congress passing a bill forcing electric utilities to convert oil and natural gas capacity to coal in response to the oil embargo of 1973-1974.<sup>31</sup> Nuclear capacity grew beginning around 1965 while hydro capacity remained roughly flat throughout our sample period. These trends are consistent with the decline in fossil fuel production in nonattainment counties having been offset by increased production by new fossil fuel and nuclear plants. In the empirical analysis, we directly explore these relationships.

## 4.2 Empirical Strategy

We use a difference-in-differences approach to examine how different annual plant-level outcomes  $Y_{it}$  vary across counties in versus out of attainment with pollutant standards set

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<sup>29</sup>Specifically, we define “nonattainment” counties as those that ever went out of attainment during the post-1971 period and attainment counties as those that never went out of attainment. Appendix Figure C.3 plots the annual proportion of fossil fuel fired electricity generation produced in ever-nonattainment counties, separately for existing versus new plants. The top panel considers nonattainment with any pollutant while the bottom panels plots nonattainment by pollutant.

<sup>30</sup>Similar descriptive plots broken down by vintage group and the number of years a plant faced nonattainment are displayed in Appendix Figure C.5. The corresponding plots for PU-TFP are displayed in Appendix Figures C.6 and C.7. The distribution of the number of years of a county in nonattainment is displayed in Appendix Figure C.8.

<sup>31</sup>The oil price shocks occurred in 1973 and 1979. Regarding natural gas, “[i]n reaction to the oil embargo of 1973-74, Congress (...) mandated the implementation of a national program to conserve petroleum products and natural gas and increase the use of coal by major fuel consumers. (...) [It] directs FEA [Federal Energy Administration] to prohibit certain powerplants and authorizes FEA to prohibit certain major fuel burning installations from burning natural gas or petroleum products as a primary energy source. Such prohibitions effectively mandate the use of coal” (EPA, 1977, p.19).

forth by the National Ambient Air Quality Standards (NAAQS). Equation (1) estimates the effect of nonattainment with any pollutant standard on the plant outcome of interest:

$$\log(Y_{it}) = \alpha_i + \delta_{ft} + \lambda_{vt} + \theta_{st} + \beta Nonattain_{ct} + \epsilon_{it} \quad (1)$$

where  $i$  indexes a plant located in county  $c$  in state  $s$ , and  $t$  indexes year-of-sample. We include plant fixed effects  $\alpha_i$ , fuel-type-by-year fixed effects  $\delta_{ft}$ , vintage-group-by-year fixed effects  $\lambda_{vt}$ , and state-by-year fixed effects  $\theta_{st}$ . This structure of fixed effects controls for a variety of time-constant and time-varying unobserved heterogeneity. For example, it accounts for the technology to generate electricity and control pollution available at the time each plant was built, statewide energy and pollution control policies that might have been implemented before or after the CAA, fuel price shocks such as the oil and natural gas shocks in the 1970s, and improvements in power plant and emission control technology that becomes available for each vintage group over time. Based on the passage of the 1963 Clean Air Act, we consider two vintage groups in our main analysis: plants built before 1963, and plants built from 1963 to 1971.<sup>32</sup>

The independent variable of interest in Equation (1) is  $Nonattain_{ct}$ , an indicator that takes on the value one if the county is out of attainment with the NAAQS for any pollutant. Because of the variation in the timing of the treatment, we report and discuss the Goodman-Bacon decomposition in the results section (Goodman-Bacon, 2018). Event study analysis that motivate this difference-in-differences approach is also reported in the results section and supports the parallel trends assumption. When examining heterogeneity of our overall effects, we interact  $Nonattain_{ct}$  with other variables of interest such as vintage groups and number of years a county has been in nonattainment. Unless otherwise noted, all our estimated coefficients are accompanied by standard errors that are two-way clustered by county and year (Cameron, Gelbach and Miller, 2011).

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<sup>32</sup>The post-1971 vintage group is only incorporated in the analysis of the adoption of emission control technologies, and when we compare our main results with estimates from approaches and sample periods considered in prior studies.

## 5 Impacts of the CAA on Power Plant Outcomes

### 5.1 Impacts on Power Plant Output, Inputs, and PU-TFP, and Evidence of Anticipatory Effects

We begin by presenting event study graphs to motivate the regression analyses that follow. These graphs are derived from the estimation of versions of Equation (1) that take the first year in nonattainment as year zero in event time, and allows the coefficients to vary from  $t \in \{-7, +10\}$  in event time. The figures plot these coefficients and their 95 percent confidence intervals. Event studies are presented for two outcomes, output and pollution-unadjusted total factor productivity (PU-TFP), and for three plant vintage groups – all plants built before 1972, plants before 1963, and plants built from 1963 to 1971.

Figure 2 highlights three key points. First, all panels show little evidence of differential trends in the years preceding the first year in nonattainment. Second, changes in the county attainment status lead to output and PU-TFP declines for existing plants in the years following nonattainment. Third, the declines appear to be driven by plants built before 1963. The coefficients of both output and PU-TFP of plants built from 1963 to 1971 look relatively flat around zero, suggesting that those plants might have made adjustments ahead of the impending air quality regulations.

Table 1 presents the estimates of  $\beta$  from Equation (1) for various plant-level outcomes. Panel A reports the average effects. Panel B reports the heterogeneous effects across plants built before and after 1963.

Panel A shows that power plants located in nonattainment counties experienced relative decreases in output and PU-TFP (cols. 1, 2). The effects are statistically significant and large in magnitude. We also find that plants in nonattainment counties experienced relative decreases in inputs (cols. 3-5). We estimate significant negative effects of nonattainment status on energy inputs (BTUs) and capacity. Meanwhile, the effects on employment are negative but small in magnitude and not statistically significant.

The negative effects of nonattainment status on plant PU-TFP are driven by the large declines in plant output that were not offset by proportional decreases in inputs. These patterns are consistent with the challenges of adjustment to power plant inputs.

Plant capacity could not be reduced in response to regulatory requirements and the number of employees required for plant operations was largely independent of output levels.<sup>33</sup> Meanwhile, power plants forced to reduce their output due to environmental regulations may have required more fuel per MWh of electricity production because they are producing at technically suboptimal levels, and because they are likely being forced to start up or ramp up production more often.

Table 1, Panel B, shows that negative effects on output and PU-TFP were driven entirely by power plants built before 1963. The heterogeneity in these effects is striking. For plants built before 1963, the coefficient estimates are large and statistically significant. For plants built from 1963 to 1971, the estimates are negative, but small in magnitude and not statistically significant.<sup>34</sup>

The divergent effects across plants built before 1963 and plants built from 1963-1971 is consistent with historical evidence on the role of the 1963 CAA in signaling future environmental regulation. Indeed, there is substantial historical evidence suggesting that power plants that opened in the post-1963 period were already incorporating anticipated regulatory requirements into plant design and locational decisions (see Section 2.1). This anticipatory behavior appears to have substantially mitigated the ultimate impact of subsequent impacts of nonattainment status on plant outcomes.

*Robustness Checks.* In Appendix Table D.2, we show that the estimated impacts of nonattainment on power plant output and PU-TFP remain statistically similar if we: (i) include utility fixed effects rather than plant fixed effects, (ii) focus on larger plants, (iii) consider only plants that primarily burn coal, (iv) drop gas-fired plants, and (v) exclude states that had set air quality standards by 1966.<sup>35</sup> Appendix Table D.3

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<sup>33</sup>The negative effects on capacity reported in column 5 reflect a decrease in the rate of growth in nonattainment relative to attainment counties. Meanwhile, plant managers in nonattainment counties may actually have required additional workers whose roles were geared towards environmental compliance.

<sup>34</sup>Appendix Table D.1 presents estimates of the impacts of nonattainment separately for plants built between 1938-1954, 1955-1962, 1963-1966, 1967-1969 and 1970-1971. These estimates suggest that the bulk of the impacts stem from plants built before 1955, suggesting in turn that even plants built after the 1955 might have been able to partially anticipate impending environmental regulations. That being said, the estimated reduction in PU-TFP due to nonattainment for plants built between 1955-1962 is statistically significant and negative.

<sup>35</sup>There was great reluctance by states to set air quality standards until forced to do so by the National Ambient Air Quality Standards (NAAQS). Prior to 1960 there were no state air quality or deposited matter standards. By 1966, ten states – California, Colorado, Delaware, Missouri, Montana, New York, Oregon, Pennsylvania, South Carolina, and Texas – had adopted ambient air quality standards for a

demonstrates that the findings are also robust to balancing the panel prior to estimating the specifications; thus, our results do not seem to be driven by plant entry or exit in response to nonattainment. Finally, Appendix Table D.4 provides evidence that the estimated reduction in PU-TFP due to nonattainment remain similar across a variety of different ways to estimate productivity.

*Heterogeneity Analysis.* Appendix Table D.5 presents estimates of the impact of nonattainment on outcomes separately for plants whose primary fuel type is coal, oil, versus natural gas. The effects are largest for natural gas, followed by coal, with no statistical effects of nonattainment on outcomes for oil-fired plants. Though gas does not emit much local pollution relative to coal or oil, burning gas can emit carbon monoxide. Moreover, natural gas was expensive during our sample period and gas-fired plants tended to be small. The FPC report of 1970 indeed states that the “[u]se of natural gas for new generating units, although desirable from a pollution standpoint, is being strongly discouraged because of the short supply” (FPC, 1972, p. xi). Therefore, utilities may have scaled down production by natural gas plants, replacing it with other sources, in response to county-level nonattainment.

Appendix Table D.6 reports estimates of the impacts of nonattainment on outcomes separately for the pollutant standards that the existing plants may experience county-level noncompliance. The table documents that the majority of the effects in our primary specifications may be driven by noncompliance with the standards associated with ambient ozone and nitrogen dioxide, which is strongly tied to ozone formation. This pattern may reflect the fact that the share of output from plants located in counties in nonattainment with these pollutants was the highest for most of our sample period, as plotted in Appendix Figure C.3.

## 5.2 Evidence of (Lack of) Adaptation By Existing Plants to Air Quality Standards

Do innovation and adaptation among existing plants mitigate the detrimental impacts of environmental regulation over time? The striking heterogeneity in effects *across* plants of different vintages suggests that anticipatory behavior mitigated the impact of nonattainment of 14 substances, and for deposited matter (Stern, 1982).

ment status among plants that opened in the post-1963 period. Nevertheless, it is unclear the extent to which existing producers – either those that opened pre- or post-1963 – were able to alter production processes and adapt to regulatory requirements imposed under the CAA. In this section, we exploit the extended lifespan of power plants to explore the evolving impacts of the CAA on existing producers.

Figure 2 (a, d) shows no evidence that existing plants adapted to environmental regulation. Estimated decreases in output and PU-TFP grow larger in size over the first 5-6 years after the county first goes into nonattainment before leveling off. Decomposing these effects across plants that opened pre-1963 (b, e) and post-1963 (c, f), we find that the long-run decreases in output and PU-TFP were driven by older vintage plants. There are no negative effects of nonattainment status on newer vintage plants in either the short, medium, or long run.

Table 2 reports the coefficient estimates from a generalized version of Equation (1), in which we allow the effects of current nonattainment status to vary according to the cumulative years of nonattainment ( $\leq 5$ , 6-10, and  $>10$ ). We estimate these regressions separately for plants built prior to 1963 and those built from 1963 to 1971.

Panel A shows no evidence of adaption among older vintage power plants. Estimated losses in output and PU-TFP are substantial and persistent. For plants in counties that were out of attainment for more than 10 years, estimated output losses are 40 percent and estimate PU-TFP losses are 27 percent, substantially larger than the initial effects of nonattainment status. Although the effects of nonattainment status on inputs magnify with cumulative exposure, the decreases are not commensurate with the output declines, which explains the compounding effects on PU-TFP.

In contrast, Panel B shows no impact of nonattainment status on the operations of new vintage power plants in the short, medium, or long-run. The coefficient estimates are small and statistically insignificant.

What explains the persistent negative effects on pre-1963 plants? The initial expansion in effects may be due in part to evolving enforcement. Indeed, following a nonattainment designation, states were permitted 18-36 months to submit a State Implementation Plan (SIP) to reduce pollution levels, and state regulators typically gave plants some time to implement the compliance strategy.

The results in Table 2 show no evidence of adaptation among existing producers in response to environmental regulatory requirements. These persistent effects of the CAA regulations on firm outcomes contrast with prior research suggesting that innovation may respond to CAA regulatory pressure (e.g., Popp, 2003, 2006). Given the limited scope to adjust power plant operations and the high retrofit cost to install pollution abatement technology, however, existing plants were likely unable to take advantage of these new innovations. Instead, adaptation occurred primarily *across* producers, as newer vintage plants seemed to anticipate future regulatory requirements and took steps to mitigate their eventual impact.

### 5.3 The Importance of Data From Before the 1970 CAA on the Estimated Impacts on Plant Outcomes

All of the results thus far have focused on existing plants built before 1972, and have used data spanning 1938-1994. However, the vast majority of studies examining the impacts of the National Ambient Air Quality Standards (NAAQS) utilize data beginning after the enactment of the Clean Air Act (CAA) of 1970. To assess the importance of data from before 1972 for the identification of the impacts of nonattainment with the NAAQS on firm outcomes, we re-estimate our primary specifications using data on existing plants from 1972-1994 in column 2 of Table 3. For convenience, the estimated impacts of nonattainment on output and PU-TFP using the full sample are reproduced in column 1.

The difference in the estimates reported in columns 1 and 2 of Table 3 highlight the importance of having baseline data from before the implementation of the CAA. If a researcher only had access to data from after the implementation of the CAA, they would conclude that existing plants *increased* rather than decreased output and PU-TFP in response to nonattainment. Intuitively, studies using data beginning after 1972 utilize only variation from counties that alternate between attainment and nonattainment status. Nevertheless, only half of the power plants in our sample are located in counties that switch attainment status between 1972 and 1994; the remainder either always face attainment or always face nonattainment between 1972-1994. By using data from 1938-1994, we are able to capture the effect of nonattainment on outcomes using variation from plants located in counties that moved from attainment to nonattainment in 1972

but never switched back to attainment during our sample period. In fact, this might be one of the reasons why the 11% relative reduction in PU-TFP in nonattainment counties found in Table 1 is over twice as large as those found in Greenstone, List and Syverson (2012). Naturally, fossil-fuel power plants are large emitters even relative to other large, stationary point sources such as manufacturing plants, which are the focus of their study.<sup>36</sup> Notwithstanding, the fact that their sample period is 1972-1993 may preclude them from obtaining estimates that take into account the pre-regulation baseline.

Figure 3 plots the nonattainment effects on output and PU-TFP by first year of data in the sample, and reinforces the importance of pre-1970 data. The estimates are negative and stable if the sample starts in 1938 or any following year until approximately 1955. The effects diminish slightly if the sample begins in the late 1950s and early 1960s, and converge rapidly towards zero if it starts in the period post-1963. Given that most of the previous studies in the literature have information starting after 1963, it is likely that their estimated impacts are biased towards zero. Appendix Figure D.1 breaks these results down by plant vintage groups. Not surprisingly, the changes in the estimated nonattainment effects occur primarily for the pre-1963 plants.

One may be concerned that the difference in the magnitude of the effect when estimating the models for the sample period 1938-1994 versus 1972-1994 is driven by plants shutting down early in response to facing nonattainment. This does not seem to be the case from examining the trends in total capacity across counties that ever versus never face nonattainment between 1972-1994 (see Figure 1b). Appendix Table A.3 also provides descriptive evidence that the number of years that a plant is in operation is *positively* associated with either ever facing nonattainment between 1972-1994 or the number of years facing nonattainment between 1972-1994. The plants built before 1963 are even more strongly associated with a longer lifespan. This positive association suggests that, if anything, electric utilities are running plants built before 1972 in nonattainment counties longer to avoid having to build new fossil-fuel plants that would be subject to the stricter New Source Performance Standards regardless of the county attainment status.

We provide two additional pieces of evidence that having pre-regulation data is crucial. First, we show that the bulk of our estimated reductions in output and PU-TFP stem

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<sup>36</sup>In 1976, for example, “the 688 large coal- and oil-fired plants in the U.S. emit nearly 60% of the total national emissions of sulfur oxides and are heavy contributors to ambient particulate loadings” (EPA, 1977, p. 12).

from existing plants that first faced nonattainment between 1972-1977. Appendix Table D.7 presents estimates of the impact of nonattainment on outcomes separately for existing plants that first faced nonattainment between 1972-1977, 1978-1983, or 1984-1994. Given that most of the effects are for 1972-1977, it would be difficult to identify the effect of nonattainment without baseline data from prior to 1972.

Second, we use a Goodman-Bacon (2018) decomposition to show that the majority of the estimated effects stem from a comparison of plants that have versus have never faced nonattainment. Appendix Table D.3 decomposes our overall difference-in-differences estimates into the three components proposed by Goodman-Bacon (2018): (i) the effect of first-nonattainment on outcomes using plants that never faced nonattainment as the control group, (ii) the effect for plants first facing nonattainment earlier in the sample using plants first facing nonattainment later in the sample as the control group, and (iii) the effect for plants first facing nonattainment later in the sample using plants first facing nonattainment earlier in the sample as the control group.<sup>37</sup> Previous work using data from after the implementation of the CAA relies on switches in attainment status over time, i.e., the last two categories listed above. Yet, the results of the Goodman-Bacon decomposition indicate that the majority of the estimated effects of first-nonattainment on outcomes stem from a comparison of plants that have versus have never faced nonattainment, rather than from differential timing in changes in attainment status. Approximately 7 percent of the existing plants faced nonattainment in every year between 1972-1994; the counties where they were located switched from attainment to nonattainment only once during our sample period – in the year 1972, when the CAA was implemented. On the other hand, about 35 percent of existing plants were located in counties that were always in attainment over the period 1972-1994. We can leverage the key variation generated by those counties only because we have historical data from before 1972.

When we estimate the specification using data from new plants built after 1972 in column 3 of Table 3, the effects of nonattainment on output and PU-TFP are somewhat smaller than our main estimates – and not statistically significant. This is not surprising because most, if not all, fossil-fuel power plants built after the enactment of the 1970

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<sup>37</sup>To conform to the specification considered in Goodman-Bacon (2018), we define treatment to be the first nonattainment rather than time-varying nonattainment, and we construct a balanced panel, as discussed in the notes of Appendix Table D.3.

CAA Amendments faced technology mandates aiming at minimizing or eliminating emissions. As part of the stricter New Source Performance Standards, plants located both in attainment and nonattainment counties all had to comply with such standards to avoid air quality deterioration. Plants built after the 1977 CAA Amendments, in particular, all had to install flue gas desulfurization devices, also known as “scrubbers,” which are the most costly technologies to reduce emissions.

## 5.4 Alternate Margins of Adjustment to the CAA

### 5.4.1 No Evidence of Production Spillovers from Plants in Nonattainment to Attainment Counties

It is possible that electric utilities respond to the CAA by shifting generation from plants in nonattainment counties to those operating under less stringent regulation in attainment counties. The relative decrease in output among plants in nonattainment counties may partly reflect this shift in operations (see columns 1 and 2 of Appendix Table D.2). In the short-run, however, these adjustments may be limited by existing excess generating capacity among plants in attainment counties. There was little scope for these plants to expand capacity without facing additional regulatory burden under the New Source Review.

To explore cross-county shifts in electricity generation, we assess whether the output of plants in attainment counties was affected by the nonattainment status potentially faced by nearby plants. We estimate the following equation for output  $Y_{it}$  for power plants located in counties that were always in attainment over the sample period 1938-1994:

$$\log(Y_{it}) = \alpha_i + \delta_{ft} + \lambda_{vt} + \beta \text{PropNonAttain}_{st} + \epsilon_{it}, \quad (2)$$

where  $i$  represents a plant from vintage group  $v$ , burning primary fuel  $f$ , and located in state  $s$ ; as before,  $t$  indexes year-of-sample. The equation includes plant fixed effects  $\alpha_i$ , fuel-type-by-year fixed effects  $\delta_{ft}$ , and vintage-group-by-year fixed effects  $\lambda_{vt}$ .

We measure plant  $i$ ’s exposure to nonattainment,  $\text{PropNonAttain}_{st}$ , in three different ways. The first measure is the annual state-level proportion of fossil-fuel-fired electricity

generating capacity in nonattainment counties. The second measure is the proportion of fossil-fuel-fired capacity in nonattainment counties owned by the same utility in the year. Finally, for each plant  $i$  in county  $c$  in year  $t$ , we calculate the proportion of fossil-fuel-fired capacity in nonattainment in year  $t$  among neighboring counties.

Table 4 reports the results and shows no evidence of local shifts in production towards attainment counties. If anything, the point estimates, while noisy, are consistently negative across the various measures of local exposure. The absence of cross-border spillovers in electricity generation contrasts with previous work showing large effects of nonattainment on the geographic patterns of industrial activity (Henderson, 1996; Becker and Henderson, 2000; Gibson, 2019). Our findings likely reflect the various geographic constraints facing electric utilities. First, unlike other sectors, power plants are immobile because of the interdependency with the placement of the power grid, and the well-defined service territory delineated by the state public utility commission. Second, short-run adjustments were severely constrained by the generating capacity of existing plants in attainment counties, which may have already been producing near peak load. Third, there was little scope for plants in attainment counties to expand capacity without the threat of regulatory intervention under the New Source Review.

Instead, Figure 1 and Appendix Figure C.4 suggest that an increasing share of electricity demand was met by new fossil fuel and nuclear plants built in the 1970s. In fact, Appendix Table D.8 provides suggestive evidence that new fossil fuel and nuclear power plants were more likely to be built in states with a larger annual proportion of the state’s population living under nonattainment.

#### 5.4.2 Fuel Switching and Scrubbers

Power plants may also adjust to nonattainment status by switching to “cleaner” fuels and/or adopting emission control technologies. By switching from bituminous coal with high sulfur and heat contents to sub-bituminous coal with lower sulfur and heat contents, existing coal-fired plants can reduce emissions levels. Existing plants can also respond to nonattainment by installing pollution abatement technology. Our analysis focuses on the adoption of flue gas desulfurization (FGD) units, colloquially known as “scrubbers.” This technology reduces oxides of sulfur emissions by over 90 percent. Because the New Source Performance Standards (NSPS) mandates the installation of FGD units in all new

plants, especially those built after the 1977 CAA Amendments, the analysis below aims at examining how nonattainment with the NAAQS and the NSPS impact the decision to install scrubbers.

Table 5 indicates that coal-fired power plants in nonattainment counties incur higher coal prices per mmBTU than plants in attainment counties. The estimates are obtained by replacing the dependent variable in Equation (1) with logged coal prices. The primary source of sub-bituminous coal in the United States is the Powder River Basin (PRB) in Montana and Wyoming. The delivered price per mmBTU of PRB coal is higher than Appalachian bituminous coal, both because transportation costs are typically higher from PRB to the plant and because PRB coal has a lower heat content, i.e., less heat in mmBTU per ton of coal.<sup>38</sup> In column 1, the sample with all coal power plants built before 1972, the increase in coal prices is of 3.5 percent. This estimated impact seems to be driven by coal plants built before 1963, as reported in column 2, although the imprecise estimate for plants built from 1963-1971 is quantitatively similar. The impact seems to increase with the cumulative number of years of exposure to nonattainment, as reported in column 3, corroborating the lack of adaptation to environmental regulation discussed in subsection 5.2.

To examine the installation of scrubbers, we estimate the following equation using all plants over our entire sample period 1938-1994:

$$\begin{aligned}
1[IS_i \leq t] = & \delta_{ft} + \theta_{st} + \gamma 1[FirstNonAttain_c \leq t] \\
& + \beta_1 1[Existing\_Prior1963_i] + \beta_2 1[Existing\_1963\_1971_i] \\
& + \delta_1 (1[FirstNonAttain_c \leq t] \times 1[Existing\_Prior1963_i]) \\
& + \delta_2 (1[FirstNonAttain_c \leq t] \times 1[Existing\_1963\_1971_i]) + \epsilon_{it},
\end{aligned} \tag{3}$$

where  $i$  indexes plant burning fuel  $f$  located in county  $c$  of state  $s$ ; as before,  $t$  indexes year. The variable  $IS_i$  is equal to the year that the plant first installed a scrubber, and

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<sup>38</sup>As mentioned by the 1968 FPC report, “[w]hile domestic reserves of coal containing one percent sulfur are large, they are mostly located in the west, and are not economically available for supplying eastern power plants. East the Mississippi River, the limited supplies of low-sulfur coal have good coking qualities and electric utilities must compete at relatively high prices with metallurgical industries and export markets for such supplies” (FPC, 1969, pp. ix-x). Ultimately, “[t]he cost of reducing oxides of sulfur emissions—through the use of higher cost ‘cleaner’ fuels (...)—is having a decided effect on the competitive position of coal (...) for electric power generation” (FPC, 1969, p. x).

the dependent variable  $1[IS_i \leq t]$  is an indicator variable equal to one if the plant  $i$  first installed a scrubber prior to year  $t$ . The variable  $FirstNonAttain_c$  is equal to the first year that county  $c$  went out of attainment with the NAAQS; if county  $c$  never went out of attainment during our sample period, the indicator variable  $1[FirstNonAttain_c \leq t]$  is always equal to zero. The indicator variable  $1[Existing\_Prior1963]_{it}$  is equal to one if plant  $i$  was built before 1963; similarly, the indicator variable  $1[Existing\_1963-1971]_{it}$  is equal to one if plant  $i$  was built from 1963-1971. The omitted category is new plants – those built after 1972. Consequently, this specification estimates the impact of first-nonattainment on FGD adoption separately for existing plants built before 1963 and existing plants built from 1963-1971 relative to new plants built after 1972. We include fuel-type-by-year fixed effects and state-by-year fixed effects.<sup>39</sup> Finally, as in our main analysis, standard errors are two-way clustered by county and year.

Table 6 documents that existing plants are less likely to install scrubbers than new plants. Columns 1 and 3 consider all plants while columns 2 and 4 consider only plants that primarily burn coal. Scrubbers remove sulfur oxides from gases released due to the burning of fossil fuels. Thus, we hypothesize that the results are most pronounced for coal-fired plants because burning coal emits far more sulfur oxides than burning either fuel oil or natural gas. Columns 1 and 2 reveal that existing plants are less likely to install scrubbers than new plants, without meaningful differences regarding when they were built. In particular, the estimates presented in Column 2 indicate that existing coal-fired plants in attainment counties are about 30 percent less likely to install scrubbers than new coal-fired plants. This is likely because only new plants are subject to the stricter NSPS. Indeed, as alluded to above, plants built after 1978 were obligated to install a scrubber, irrespective of whether they were built in attainment or nonattainment counties. Existing plants, on the other hand, may only be forced to face NSPS if they make “significant upgrades,” which can include installing a scrubber. Thus, existing plants may forgo installing FGD units in order to avoid the need to comply with the stricter NSPS. They might only consider scrubbers as the last resort to comply with the NAAQS.

Columns 2 and 4 of Table 6 indicate that coal plants built between 1963 and 1971 may have made some adjustments in anticipation of the impending regulations. In column

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<sup>39</sup>We do not include plant fixed effects because we want to estimate the impact of being built before versus after 1972 on the decision to install pollution abatement technology.

2, the interaction coefficient on *First NA x Built Before 1963* suggests that these plants may have had no other less costly way to comply with air quality standards. In contrast, the interaction coefficient on *First NA x Built From 1963-1971* is smaller and statistically insignificant, indicating that they may have made some adjustments in anticipation of the impending regulations, avoiding the need to install scrubbers later on. The differences between plants built before 1963 and from 1963 to 1971 remain when coal plants built after 1972 are dropped from the analysis in column 4.

## 6 Aggregate Effects of the 1970 CAA on PU-TFP

In this section, we explore the national-level effects of the National Ambient Air Quality Standards (NAAQS) on pollution-unadjusted total factor productivity (PU-TFP) in the power sector. In any year  $t$ , we can calculate average PU-TFP across U.S. power plants as a simple output-weighted average:

$$\overline{PU-TFP}_t = \frac{\sum_i output_{it} \cdot PU-TFP_{it}}{\sum_i output_{it}}$$

we calculate the difference between output-weighted PU-TFP with versus without the 1970 CAA in each year between 1972-1994 using our estimates to construct the counterfactual levels of PU-TFP and output that would have prevailed if the NAAQS wasn't implemented. We denote the counterfactual PU-TFP and output for plant  $i$  in year  $t$   $PU-TFP^C$  and  $Output^C$  respectively. To calculate counterfactual PU-TFP and output, we increase observed output and PU-TFP for plants built before 1963 in nonattainment counties using the estimates from Table 2. We do not adjust observed PU-TFP and output levels for plants built between 1963-1971 given that: (1) the effects listed in Table 2 are small and not statistically significant for plants built between 1963-1971, and (2) Table 4 suggests that output does not shift from existing plants in nonattainment counties to plants in attainment counties. We also do not adjust PU-TFP in the counterfactual for plants built after 1972 because the estimate from column 3 of Table 3 suggests that the impact of nonattainment on PU-TFP for these plants is very small. That being said, we adjust the output levels for plants built after 1972 down in the counterfactual based on the simplifying assumption that output from post 1972 plants increased to compensate

for output reductions from pre-1963 plants in nonattainment counties.<sup>40,41</sup>

Our back-of-the-envelope calculation of the impact of the NAAQS on aggregate productivity is based on the following equation:

$$\Delta \overline{\text{PU-TFP}}_t = \sum_i \left[ \underbrace{\frac{\text{Output}_{i,t}}{\sum_i \text{Output}_{i,t}} \cdot \Delta \text{PU-TFP}_{it}}_{\text{Within-Plant Efficiency}} + \underbrace{\frac{\Delta \text{Output}_{i,t}}{\sum_i \text{Output}_{i,t}} \cdot \text{PU-TFP}_{it}}_{\text{Across-Plant Reallocation}} \right] \quad (4)$$

where  $\Delta \text{PU-TFP}_{it} \equiv \text{PU-TFP}_{it} - \text{PU-TFP}_{it}^C$  and  $\Delta \text{Output}_{it} \equiv \text{Output}_{it} - \text{Output}_{it}^C$  are the changes in PU-TFP and output respectively with the NAAQS versus without the NAAQS. Equation (4) shows that the NAAQS can affect national productivity via two channels. The first channel,  $\frac{\text{Output}_{i,t}}{\sum_i \text{Output}_{i,t}} \cdot \Delta \text{PU-TFP}_{it}$ , is a *within-plant efficiency* effect: existing plants in nonattainment counties may have lower productivity due to increased regulatory requirements. The second channel,  $\sum_i \frac{\Delta \text{Output}_{i,t}}{\sum_i \text{Output}_{i,t}} \cdot \text{PU-TFP}_{it}$ , is a *cross-plant reallocation effect*, which arises from regulatory-induced shifts in output from older plants in nonattainment to newer plants.

Figure 4 plots the annual changes with versus without the NAAQS in output-weighted PU-TFP, within-plant efficiency, and across-plant reallocation. This figure documents that the NAAQS led to an annual average national decline in PU-TFP of 6 percent over the period 1972-1994. This corresponds to annual productivity losses of \$3.5 billion in 2020 dollars.<sup>42</sup> Although sizeable, this economic cost is substantially smaller than the health benefits from improved air quality attributable to the CAA (Currie and Walker, 2019; Aldy et al., Forthcoming). Moreover, the estimated productivity losses appear to diminish with time, falling to less than 5 percent in the latter half of the sample period.

The aggregate impact of the NAAQS on PU-TFP in Figure 4 is the result of two offsetting effects. The dashed red line shows the negative *within-plant efficiency* effect over the post-1972 period. The magnitude of these aggregate productivity losses increase until 1979 but decrease thereafter. These nonuniform trends reflect several competing

<sup>40</sup>Appendix Table D.8 provides suggestive evidence in favor of this assumption.

<sup>41</sup>We assume that, under the NAAQS, reductions in output by pre-1963 plants in nonattainment counties in each year were reallocated proportionally to power plants that opened after 1972 in the same census division.

<sup>42</sup>We obtain this aggregate cost estimate by multiplying the PU-TFP effect by the total revenue earned by steam electric utilities in 1970 (Federal Power Commission, 1971).

forces. On the one hand, the productivity losses should magnify because: (1) more counties fall out of attainment over the post-1972 period, and (2) the estimated impacts on PU-TFP increase with number of years in nonattainment. On the other hand, as older plants in nonattainment counties reduce output over time, their contribution to national PU-TFP diminishes.

The dotted blue line shows the positive *cross-plant reallocation* effect over the post-1972 period. The CAA induced plants built before 1963 in nonattainment counties to gradually reallocate production to newer plants that opened in the post-1972 period. Since these newer plants were typically more efficient (see Appendix Figures A.7 and C.7), this reallocation contributed to an increase in average national PU-TFP in the power sector. This effect becomes larger over our sample period as pre-1963 plants reduced their output further. That being said, the cross-plant reallocation never becomes larger enough to fully offset the within-plant losses.

Together, our results demonstrate how reallocation across producers can substantially mitigate the aggregate economic costs of environmental regulation. Although our analysis focuses on the power sector, these patterns may carry over to a wide array of sectors and industries. To the extent that pollution is often concentrated among older and less efficient entrenched incumbents, environmental regulation may accelerate the process of reallocation towards higher productivity entrants.

## 7 Conclusion

This paper leverages newly digitized data on power plant operations from 1938 to 1994 to examine the economic impacts of the 1970 Clean Air Act (CAA) on firm behavior. The long panel allows for a benchmark period without regulation, and for anticipatory responses by electric utilities. We find that the CAA caused relatively large reductions in output and pollution-unadjusted total factor productivity. These effects were concentrated among plants that opened before 1963, when there was little scope to anticipate future regulatory requirements. In contrast, we find no negative effects on plants that opened in the post-1963 period. These results indicate that firms may be able to acquire information during the process leading up to the passage of a landmark legislation, and preemptively take actions to reduce the costs of regulatory compliance.

We also find no evidence that the impacts of nonattainment status for older plants diminished with time. These results suggest that the long-run economic impacts of environmental regulation are likely to be offset primarily through industry churn as opposed to *within-producer* adaptation and innovation. Newer entrants were able to incorporate pre-emptive investments in plant design and choose locations strategically. Hence, they may have incurred limited economic costs from subsequent environmental enforcement.<sup>43</sup>

Our findings highlight key political economy challenges for environmental regulation. As emphasized by Stigler (1971), governments are able to create rents, and regulation often generates winners and losers. To the extent that entrenched incumbent producers bear the economic costs of regulatory compliance and have disproportionate political influence, environmental policy may be enacted slowly and carve out exemptions for certain emitters (Stavins, 2006; Revesz and Lienke, 2016).

The aggregate economic costs of the Clean Air Act borne by the electricity supply sector are small in comparison to the health gains associated with improved air quality. Nevertheless, these costs are unevenly distributed across plants, and ultimately incurred by local residents through higher prices in certain utility service areas. The historical U.S. experience highlights the challenge for environmental policy design in developing countries, where policymakers often must balance the need to curb extreme levels of air pollution with the objective of promoting widespread access to affordable energy services.

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<sup>43</sup>Other efforts to reduce the impacts of government oversight may include industry self-regulation (DeMarzo, Fishman and Hagerty, 2005; Charoenwong, Kwan and Umar, 2019), lobbying and grandfathering (Stavins, 2006; Kang, 2016), and strategic and tactical actions that affect the regulation effectiveness (Lim and Yurukoglu, 2018; Abito, 2019).

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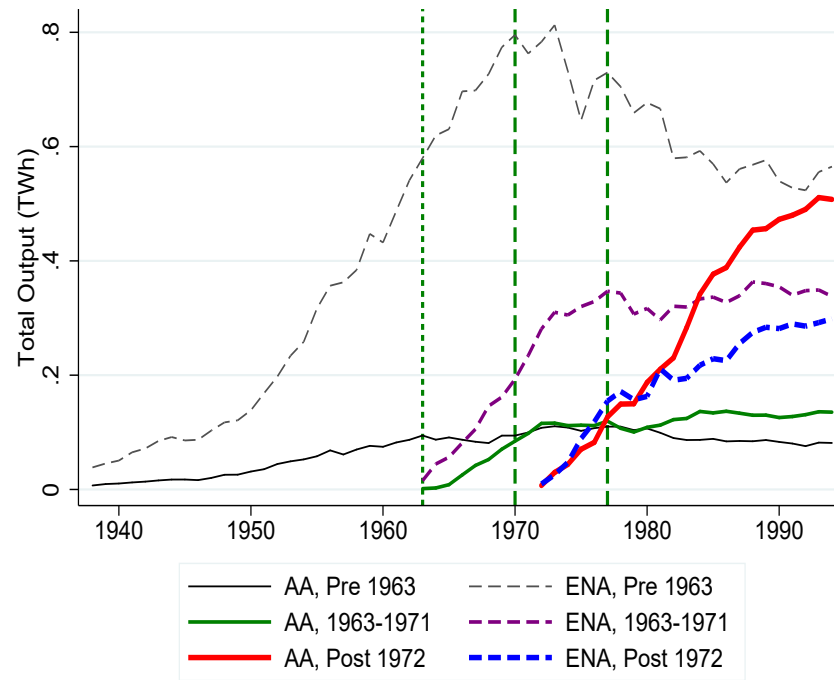
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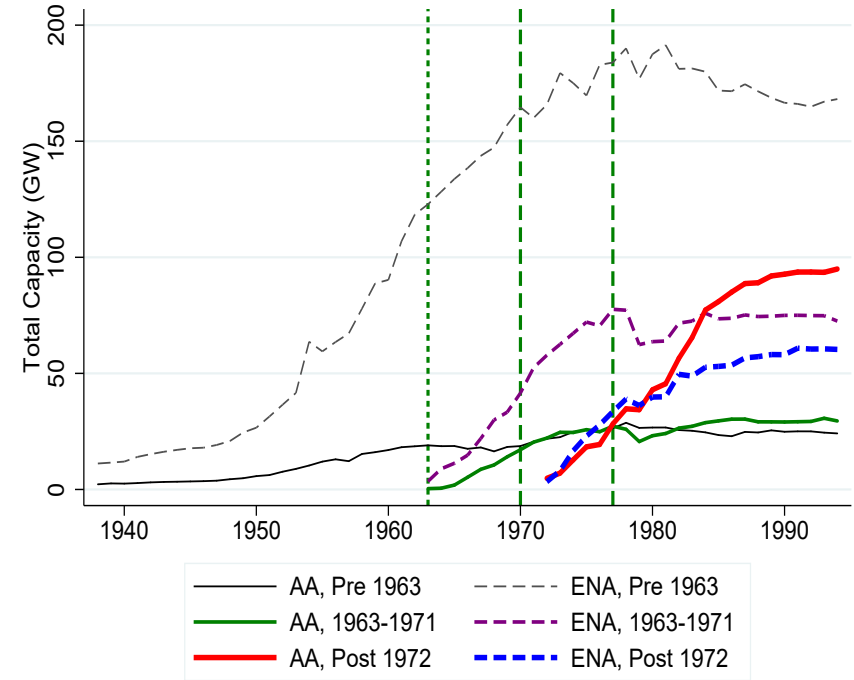
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## Figures and Tables

Figure 1: Annual Total Electricity Generation and Capacity from Fossil-Fuel Power Plants By Vintage and Attainment Status



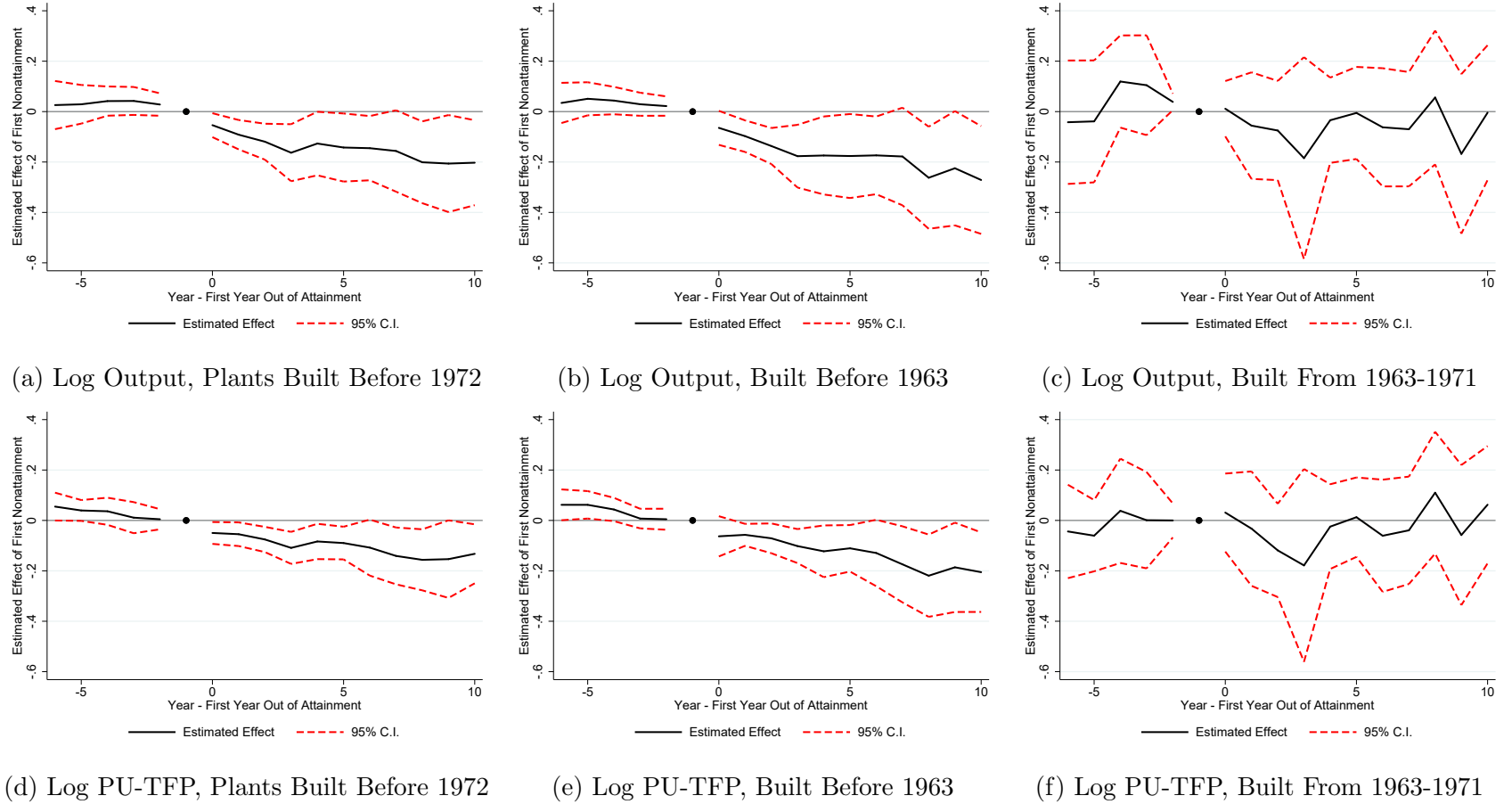
(a) Total Output



(b) Total Capacity

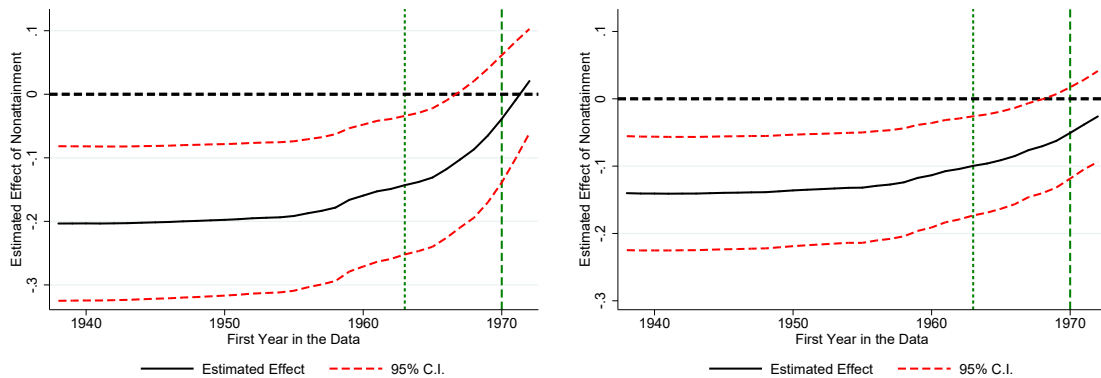
*Notes:* This figure documents annual total electricity generation produced by fossil-fuel-fired plants in the United States. Plants are located either in “ever-nonattainment” (ENA) counties that went out of attainment with the National Ambient Air Quality Standards (NAAQS) at least once during our 1938-1994 sample period, or in “always-attainment” (AA) counties that never went out of attainment over that period of analysis. We consider three plant vintage groups: plants built before 1963, plants built between 1963-1971, and plants built after 1972. The short-dashed green vertical line represents the passage of the Clean Air Act of 1963 and the dashed green vertical lines represent the passing of the Clean Air Act of 1970 and its amendments in 1977.

Figure 2: Event Study Analysis of the Impacts of First Year in Nonattainment on Power Plant Outcomes



*Notes:* This event study figure plots the estimated effect of first nonattainment on log output and the log of pollution-unadjusted total factor productivity (PU-TFP) separately for each event year. The period of analysis is 1938-1994. All specifications include plant fixed effects, state-by-year fixed effects, fuel-type-by-year fixed effects, and vintage-by-group fixed effects; plants built before 1963 are in vintage group 1 while plants built between 1963-1971 are in vintage group 2. The 95% confidence intervals reported in these figures are based on standard errors that are two-way clustered by county and year. The two leftmost panels are estimated using plants built before 1972, the middle two panels consider plants built before 1963, and the rightmost two panels focus on plants built between 1963-1971.

Figure 3: Impacts of Nonattainment on Plant Operations by Initial Sample Year

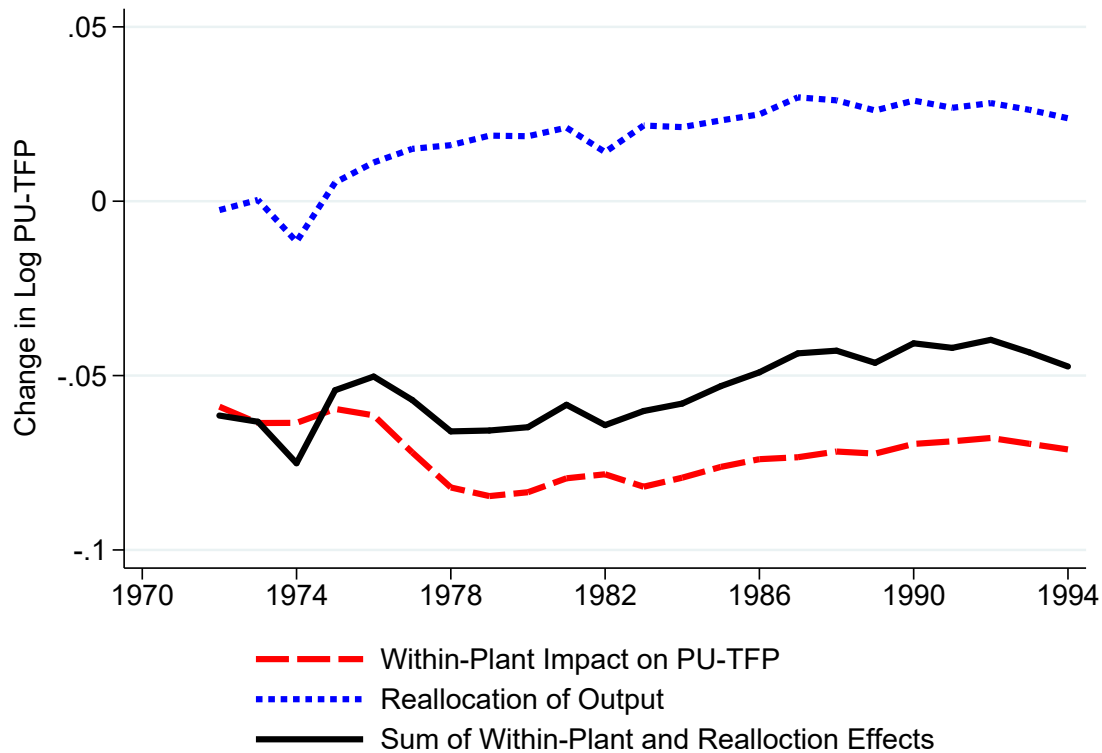


(a) Estimated Effects on Log Output

(b) Estimated Effects on Log PU-TFP

*Notes:* This figure displays the estimated impacts of nonattainment on log output and the log of pollution-unadjusted total factor productivity (PU-TFP) by initial sample year. These estimates are based on annual plant-level data from 1938-1994, considering all plants that were built before 1972. The short-dashed green vertical line represents the passage of the Clean Air Act of 1963 and the dashed green vertical lines represent the Clean Air Act of 1970 and its amendments in 1977. All specifications include plant fixed effects, state-by-year fixed effects, fuel-type-by-year fixed effects, and vintage-group-by-year fixed effects; plants built before 1963 are in vintage group 1 while plants built between 1963-1971 are in vintage group 2. The 95% confidence intervals reported in these figures are based on standard errors that are two-way clustered by county and year.

Figure 4: Nationwide Effects of the 1970 CAA on Power Plant Productivity



*Notes:* This figure depicts the estimated nationwide effects of the 1970 CAA on power plant productivity based on the methodology described in Section 6. The aggregate impact of the CAA on pollution-unadjusted total factor productivity (PU-TFP), represented by the solid black line, is a result of two offsetting effects. The long-dashed red line shows the negative *within-plant efficiency effect* over the post-1972 period, which reflects the fact that pre-1963 “existing” plants in nonattainment counties may have lower productivity due to increased regulatory requirements (see Table 2, Panel A, column 2). The short-dashed blue line shows the positive *cross-plant reallocation effect* over the post-1972 period, which arises from regulatory-induced shifts in output across plants with different productivity levels (see Appendix Table D.8). Some of the reductions in output of existing plants may have been shifted to post-1972 “new” plants, which were usually more productive (see Appendix Figures A.7 and C.7).

Table 1: Impacts of Nonattainment on Power Plant Operations from 1938-1994

Dep. Var. (in Logs):	(1) Output	(2) PU-TFP	(3) Fuel Use	(4) No. Employees	(5) Capacity
<i>Panel A. Average Effects</i>					
Nonattainment	-0.203*** (0.062)	-0.140*** (0.043)	-0.115* (0.058)	-0.033 (0.031)	-0.102** (0.039)
R <sup>2</sup>	0.819	0.616	0.751	0.864	0.914
<i>Panel B. Effects by Plant Vintage</i>					
NA × 1[Before 1963]	-0.230*** (0.069)	-0.163*** (0.050)	-0.138** (0.065)	-0.033 (0.035)	-0.119*** (0.044)
NA × 1[1963-1971]	-0.063 (0.089)	-0.019 (0.070)	0.012 (0.085)	-0.030 (0.055)	-0.015 (0.049)
R <sup>2</sup>	0.819	0.616	0.751	0.864	0.914
Plant FE	Y	Y	Y	Y	Y
State By Year FE	Y	Y	Y	Y	Y
Fuel Type By Year FE	Y	Y	Y	Y	Y
Vintage By Year FE	Y	Y	Y	Y	Y
Mean Dep. Var.	6.736	-0.621	9.168	4.498	5.474
Number of Obs.	22,134	22,134	22,134	22,134	22,134
Number of Plants	686	686	686	686	686

*Notes:* This table reports the impacts of nonattainment on power plant operations over the period 1938-1994. The unit of observation for the regressions in this table is plant-year, and the estimation considers all plants that were built before 1972. Panel A estimates how annual plant-level outcomes change with the annual attainment status of the county where the plant is located. Panel B estimates the impact of nonattainment on outcomes separately for plants built before 1963 versus plants built from 1963-1971. For all specifications, “nonattainment” is defined as the county being out of attainment with the NAAQS for any pollutant in the year. All specifications include plant fixed effects, state-by-year fixed effects, fuel type by year fixed effects and vintage group by year fixed effects; plants built before 1963 are in vintage group 1 while plants built between 1963-1971 are in vintage group 2. PU-TFP stands for pollution-unadjusted total factor productivity, and NA for nonattainment. Standard errors in parentheses are two-way clustered by county and year. \*\*\* denotes statistical significance at the 1% level, \*\* at the 5% level, and \* at the 10% level.

Table 2: Impacts of Nonattainment by Vintage and Years in Nonattainment

Dep. Var. (in Logs):	(1) Output	(2) PU-TFP	(3) Fuel Use	(4) No. Employees	(5) Capacity
<i>Panel A. Effects for Plants Built Before 1963</i>					
Years in NA $\leq 5$	-0.100 (0.084)	-0.141*** (0.051)	0.003 (0.082)	0.068 (0.044)	-0.030 (0.054)
Years in NA $\in [6, 10]$	-0.248** (0.118)	-0.221*** (0.079)	-0.030 (0.113)	0.013 (0.057)	-0.127* (0.066)
Years in NA $> 10$	-0.370** (0.140)	-0.285*** (0.095)	-0.212 (0.133)	0.010 (0.076)	-0.243*** (0.085)
R <sup>2</sup>	0.799	0.614	0.724	0.858	0.903
Mean of Dep. Var.	6.608	-0.665	9.053	4.491	5.357
Number of Obs.	19,063	19,063	19,063	19,063	19,063
Number of Plants	559	559	559	559	559
<i>Panel B. Effects for Plants Built From 1963-1971</i>					
Years in NA $\leq 5$	-0.066 (0.122)	0.018 (0.097)	-0.041 (0.102)	-0.048 (0.071)	-0.044 (0.061)
Years in NA $\in [6, 10]$	-0.025 (0.129)	0.109 (0.099)	0.013 (0.122)	-0.075 (0.088)	-0.080 (0.077)
Years in NA $> 10$	-0.116 (0.174)	0.032 (0.144)	-0.012 (0.162)	-0.106 (0.114)	-0.037 (0.094)
R <sup>2</sup>	0.903	0.679	0.890	0.929	0.961
Mean of Dep. Var.	7.596	-0.345	9.960	4.591	6.259
Number of Obs.	2,714	2,714	2,714	2,714	2,714
Number of Plants	121	121	121	121	121
Plant FE	Y	Y	Y	Y	Y
State By Year FE	Y	Y	Y	Y	Y
Fuel Type By Year FE	Y	Y	Y	Y	Y
Vintage By Year FE	Y	Y	Y	Y	Y

*Notes:* This table report estimates of the impact of nonattainment on power plant operations separately for bins defined by the cumulative number of years that a plant has faced nonattainment. The unit of observation for the regressions in this table is plant-year. For both panels, we interact the indicator for nonattainment with three bins defined by whether the plant has cumulatively faced nonattainment in five or fewer years, six to ten years, or more than ten years as of the year-of-sample. We focus on plants built before 1963 in the top panel while the bottom panel considers plants built between 1963-1971. All specifications include plant fixed effects, state-by-year fixed effects, fuel type by year fixed effects and vintage group by year fixed effects; plants built before 1963 are in vintage group 1 while plants built between 1963-1971 are in vintage group 2. PU-TFP stands for pollution-unadjusted total factor productivity, and NA for nonattainment. Standard errors in parentheses are two-way clustered by county and year. \*\*\* denotes statistical significance at the 1% level, \*\* at the 5% level, and \* at the 10% level.

Table 3: Comparison of Estimates for Existing and New Plants  
Using Sample Periods 1938-1994 versus 1972-1994

	(1)	(2)	(3)
<i>Panel A. Effects of Nonattainment on Log Output</i>			
Nonattainment	-0.203*** (0.062)	0.021 (0.042)	-0.042 (0.110)
R <sup>2</sup>	0.819	0.891	0.950
Mean of Dep. Var.	6.736	7.050	7.650
<i>Panel B. Effects of Nonattainment on Log PU-TFP</i>			
Nonattainment	-0.140*** (0.043)	-0.026 (0.034)	-0.010 (0.079)
R <sup>2</sup>	0.616	0.717	0.825
Mean of Dep. Var.	-0.621	-0.736	-0.509
Number of Obs.	22,134	10,584	2,221
Number of Plants	686	580	185
Plant FE	Y	Y	Y
State By Year FE	Y	Y	Y
Fuel Type By Year FE	Y	Y	Y
Vintage By Year FE	Y	Y	Y
Type of Plant	Existing	Existing	New
Sample Period	1938-1994	1972-1994	1972-1994

*Notes:* This table reports the estimated impacts of nonattainment on the outcomes of existing and new plants over alternative periods of analysis. Panel A reports the impact of nonattainment on the log of output while Panel B reports the impact on the log of pollution-unadjusted total factor productivity (PU-TFP). The unit of observation for the regressions in this table is plant-year. For all specifications, “nonattainment” is defined as the county being out of attainment with the NAAQS for any pollutant in the year. Column 1 of both panels is estimated for the sample period 1938-1994 considering all “existing” plants built before 1972. Column 2 of both panels is estimated for the sample period 1972-1994 focusing on all “existing” plants. Column 3 of both panels is estimated for the sample period 1972-1994 focusing on all “new” plants built after 1972. All specifications include plant fixed effects, state-by-year fixed effects, fuel type by year fixed effects and vintage group by year fixed effects; plants built before 1963 are in vintage group 1, plants built between 1963-1971 are in vintage group 2, and plants built after 1972 are in vintage group 3. Standard errors in parentheses are two-way clustered by county and year. \*\*\* denotes statistical significance at the 1% level, \*\* at the 5% level, and \* at the 10% level.

Table 4: Impact of Nonattainment on Log Output: Spillovers

Dep. Var.: Log Output	(1) Cap-Weighted	(2) Utility-Level	(3) Adjacency
Spillover Nonattainment	0.039 (0.255)	0.032 (0.276)	-0.204 (0.193)
R <sup>2</sup>	0.826	0.830	0.820
Mean of Dep. Var.	6.049	6.107	6.014
Number of Obs.	5,437	5,087	5,598
Number of Plants	231	227	232
Plant FE	Y	Y	Y
Fuel Type By Year FE	Y	Y	Y
Vintage Group By Year FE	Y	Y	Y

*Notes:* This table reports estimates testing whether the output of plants in attainment counties varies with measures of annual county-level nonattainment in nearby counties. The unit of observation for all regressions is plant-year, considering only plants built before 1972 that never faced nonattainment between 1972-1994. The outcome considered in all columns is the log of annual plant-level output. The independent variable of interest in Column 1 is the proportion of fossil-fuel-fired electricity generating capacity in nonattainment counties in the state in the year. In Column 2, we consider the proportion of fossil-fuel-fired capacity in nonattainment counties owned by the same utility in the year. Finally, Column 3 focuses on the proportion of fossil-fuel-fired capacity in nonattainment counties adjacent to the county in the year. All specifications include plant fixed effects, fuel type by year fixed effects, and vintage group by year fixed effects; plants built before 1963 are in vintage group 1 while plants built between 1963-1971 are in vintage group 2. Standard errors in parentheses are two-way clustered by county and year. \*\*\* denotes statistical significance at the 1% level, \*\* at the 5% level, and \* at the 10% level.

Table 5: Impact of Nonattainment on Log Coal Prices

Dep. Var.: Log Coal Price	(1)	(2)	(3)
Nonattainment	0.029 (0.018)		
NA $\times$ 1[Before 1963]		0.025 (0.020)	
NA $\times$ 1[1963-1971]		0.051 (0.038)	
Years in NA $\leq$ 5			0.047** (0.020)
Years in NA $\in$ [6,10]			0.054* (0.029)
Years in NA $>$ 10			0.121*** (0.038)
R <sup>2</sup>	0.719	0.719	0.719
Mean of Dep. Var.	-0.789	-0.789	-0.789
Number of Obs.	11,160	11,160	11,160
Number of Plants	342	342	342
Plant FE	Y	Y	Y
State By Year FE	Y	Y	Y
Fuel Type By Year FE	Y	Y	Y
Vintage Group By Year FE	Y	Y	Y

*Notes:* This table presents the estimated impact of nonattainment on the log of coal prices. The unit of observation for the regressions in this table are plant-year, focusing only on plants built before 1972 and considering only years in which the plant purchased coal. All specifications include plant fixed effects, state-by-year fixed effects, fuel type by year fixed effects, and vintage group by year fixed effects; plants built before 1963 are in vintage group 1 while plants built between 1963-1971 are in vintage group 2. In Column 2, we interact nonattainment with two indicators denoting whether the plant was built before 1963 versus built between 1963-1971. In Column 3, we consider nonattainment interacted with three indicators denoting whether the cumulative number of years up to the year-of-sample that plant has faced nonattainment was less than 5 years, between 6-10 years, or more than 10 years. Standard errors in parentheses are two-way clustered by county and year. \*\*\* denotes statistical significance at the 1% level, \*\* at the 5% level, and \* at the 10% level. The unit of observation for these regressions is a plant-year.

Table 6: Impacts of Nonattainment and Plant Vintage on the Adoption of FGD

Dep. Var: 1[FGD]	(1)	(2)	(3)	(4)
1[1963-1971]	0.025 (0.017)	0.033 (0.029)	0.016 (0.016)	0.037 (0.028)
1[After 1972]	0.254*** (0.050)	0.302*** (0.060)		
First NA	0.032** (0.015)	0.055** (0.025)	0.019 (0.012)	0.055*** (0.020)
First NA $\times$ 1[1963-1971]	-0.043 (0.026)	-0.091** (0.042)	-0.035 (0.025)	-0.103** (0.041)
First NA $\times$ 1[After 1972]	-0.153** (0.059)	-0.208*** (0.074)		
R <sup>2</sup>	0.373	0.446	0.264	0.307
Mean of Dep. Var.	0.050	0.087	0.023	0.035
Number of Obs.	25,107	14,295	22,134	12,123
Number of Plants	899	504	686	346
State By Year FE	Y	Y	Y	Y
Fuel Type By Year FE	Y	Y	Y	Y
Vintage Group By Year FE	Y	Y	Y	Y
Fuel Type	All	Coal	All	Coal
Includes Plants Built After 1972	Y	Y	N	N

*Notes:* This table presents regression results measuring whether the installation of flue gas desulfurization (FGD) technology is impacted by attainment status. The unit of observation for these regressions is a plant-year. For all specifications, “nonattainment” is defined as the county being out of attainment with the NAAQS for any pollutant in the year. The dependent variable is an indicator variable that is equal to one if the plant has at least one FGD system installed in the year. Columns 1 and 3 consider all plants while Columns 2 and 4 consider only plants that primarily burn coal. All specifications include state-by-year fixed effects, fuel-type-by-year fixed effects, and vintage group by year; plants built before 1963 are in vintage group 1, plants built between 1963-1971 are in vintage group 2, and plants built after 1972 are in vintage group 3. Standard errors in parentheses are two-way clustered by county and year. \*\*\* denotes statistical significance at the 1% level, \*\* at the 5% level, and \* at the 10% level.