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Aleksandar Andonov
Joshua Rauh

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ABSTRACT

Private equity (PE), institutional investors, and foreign corporations own 58% of wind, 47% of solar, and 34% of natural gas electricity generation. These new entrants are twice as likely to create new power plants as incumbent domestic listed utilities, highlighting a new role for PE in large-scale asset creation. They also acquire existing plants. While fossil-fuel plant sales to foreign corporations extend operations, PE has similar decommissioning rates to incumbents. The new owners create more efficient plants and improve acquired ones. Market deregulation drives the results, highlighting the dual importance of competition and new financing for both creation and acquisitions.

Aleksandar Andonov
University of Amsterdam
Amsterdam Business School
a.andonov@uva.nl

Joshua Rauh
Stanford University
and Hoover Institution
and also NBER
rauh@stanford.edu

1 Introduction

Both financing sources and market competition can have profound impacts on the implementation of new technologies. The finance literature has emphasized that developing and implementing innovative technologies requires investors willing to put capital at risk, specifically venture capital, if smaller firms are to disrupt larger ones (Hall and Lerner, 2010; Nanda and Rhodes-Kropf, 2013). At the same time, the economics literature has long focused on the role of regulation and market structure in the adoption of new technologies. Schumpeter (1942) argued that a firm facing perfect competition has fewer incentives and lesser scope to adopt new technologies compared to larger firms in oligopolistic markets. Arrow (1962) in contrast argued that market power stifles innovation, as firms wish to protect their rents and avoid cannibalization of existing assets. The destruction process is also costly as incumbents face legal and regulatory risks associated with legacy technologies and stranded assets. Whether the adoption of new technologies comes more from dominant incumbents or smaller new entrants depends on the competitive and regulatory environment (Shapiro, 2011).

The U.S. electricity generation industry is well-suited to examine the role of ownership in adopting new technologies for several reasons. First, energy is a capital-intensive sector that has experienced a great deal of innovation in both renewable and traditional technologies (e.g., Gilje, Loutskina, and Strahan, 2016). Second, there is substantial variation across and within states in the regulation of electricity markets, allowing to analyze the importance of deregulation for attracting new financing sources. Third, electricity generation is central to government environmental policy and demands for reduced emissions, as well as considerations of energy independence.[1] Fourth, energy assets provide vital services and can stimulate economic growth through spillovers to other sectors (Glaeser and Poterba, 2020).

In this paper, we find that the creation of new power plants and the destruction of old ones has been driven by capital from new financial owners in the sector, especially private equity (PE), but also institutional investors and non-U.S. corporations. This occurs even though the incumbents, who are primarily domestic publicly traded investor-owned utilities (IOUs), often have significant advantages including size, synergies with existing operations, access to the transmission network, and the ability to impact government policy.[2] Our results provide novel evidence of the role of PE in large-scale asset creation, in contrast to PE's role in acquiring and restructuring existing assets

[1] The International Energy Association (2021) calculated that energy investments would have to rise to $5 trillion per year by 2030 to achieve net zero emissions by 2050.

[2] Much of the literature on increasing concentration and rise of large firms has emphasized these advantages of large incumbents more generally (e.g., Chandler, 1994; Autor et al., 2020; Kwon, Ma, and Zimmermann, 2023).

(Kaplan and Strömberg, 2009; Gompers, Kaplan, and Mukharlyamov, 2016; Davis et al., 2014). In this setting as well, we show that PE improves operating efficiency. The gap between the incumbents and PE in both creation and acquisition is concentrated in electricity markets that are deregulated, highlighting an interaction between market deregulation and new financing sources.

Using a unique and novel dataset on the ownership of U.S. power plants, we begin by documenting that over the 2005–2020 period the ownership share of publicly traded U.S. investor-owned utilities (IOUs) has declined from 70% to 54%, while total U.S. electricity generation has remained constant at 4.1 trillion kWh per year. PE, institutional investors, and foreign listed corporations have gradually replaced domestic public IOUs in the ownership of both renewable and fossil fuel plants. As of 2020, these new entrants together owned 58% of wind, 47% of solar, 34% of natural gas, and 10% of coal electricity production.

To study the causes and consequences of this shift, we analyze three questions. First, to what extent do the ownership changes occur due to financing of new assets versus sales and decommissioning of existing assets? This sheds light on whether the ownership shift is primarily about who is creating new assets (Aghion, Van Reenen, and Zingales, 2013; Kortum and Lerner, 2000) as opposed to who is acquiring assets to redeploy or shut them down (Jovanovic and Rousseau, 2002; Maksimovic and Phillips, 2001, 2008), and ultimately highlights a new role for PE in asset creation. Second, to what extent does deregulation versus other economic factors contribute to attracting finance from the new modes: PE, institutional investors, and foreign corporations? This relates to the finance literature on the conditions for investment by different types of owners, especially PE (Kaplan and Strömberg, 2009; Lerner, Sørensen, and Strömberg, 2011) and also foreign ownership (Ferreira and Matos, 2008; Erel, Jang, and Weisbach, 2022). Third, what are the implications of the changing ownership structure and particularly PE for power plant operating performance? This relates to the extensive literature on operational impacts of PE, such as Davis et al. (2014).[3]

We begin the analysis by examining how the ownership of power plants changes from domestic public IOUs (which we will henceforth refer to as simply IOUs) to the new owners.[4] The ownership changes could occur through three channels: creating new greenfield power plants, acquiring existing

[3]Specifically, prior research has examined the impact of PE ownership on operational performance, productivity, employment, and profitability (e.g., Davis et al., 2014; Bernstein and Sheen, 2016; Antoni et al., 2019; Davis et al., 2021; Howell et al., 2022); workplace safety, employees health, and employee satisfaction (e.g., Cohn et al., 2021; Lambert et al., 2021); environment and pollution (e.g., Shive and Forster, 2020; Bellon, 2022; Bai and Wu, 2023); customers in regulated industries such as education and healthcare (e.g., Eaton, Howell, and Yannelis, 2020; Liu, 2022).

[4]This IOU category, in addition to the publicly traded traditional utilities and independent power producers (e.g., Duke Energy, Exelon, PG&E, Southern Company, etc.), also includes yieldcos, which are public companies spun off from those traditional entities. However, we exclude a PE-acquired IOU from this category and include it as PE.

power plants, and decommissioning (shutdown of) power plants. Identifying the importance of the creation channel versus acquisition and destruction is important for understanding the role that the new finance modes are actually playing.

A Schumpeter-leaning hypothesis is that IOUs, which are the traditional incumbent owners in our setting, have competitive advantages for creating new assets, so sales of existing assets and differences in decommissioning rates would drive the ownership changes. First, many IOUs operate at least partially as regulated incumbent utilities and might receive compensation for new investments through the rate base for the fixed costs of building new assets (Averch and Johnson, 1962; Joskow and Schmalensee, 1986; Joskow, Rose, and Wolfram, 1996).[5] Second, the sales channel, which focuses on transferring ownership of existing plants, is closer to the traditional role of PE, where the new owners operate the acquired and restructured assets more efficiently. The PE acquisitions of existing assets might also free up capital for incumbent IOUs to invest in new assets. Third, sales by IOUs to PE, institutional investors, and foreign corporations also might reflect leakage. IOUs, subject to stricter disclosure rules and more public pressure (e.g., Benthem et al., 2022; Bolton and Kacperczyk, 2022; Duchin, Gao, and Xu, 2024) may sell older plants to less-regulated entities like PE (Bernstein, 2022) and foreign corporations. To the extent that the shift in ownership is driven by differences in decommissioning rates (and sales to owners with different decommissioning rates), that could indicate that the new ownership types are contributing to "leakage" by delaying decommissioning and extending the operation of older fossil fuel plants (Fowlie, Reguant, and Ryan, 2016; Copeland, Shapiro, and Taylor, 2021).

However, an alternative hypothesis is that IOUs may prefer to delay the adoption of new technology (Arrow, 1962), especially if protected by limited competition and a lack of market discipline (Bertrand and Mullainathan, 2003; Gutiérrez and Philippon, 2017; Cunningham, Ederer, and Ma, 2021; Aghion, Bergeaud, and Van Reenen, 2023). Under this hypothesis, the new investor types will be more likely to own new power plants, though not all will be equally likely due to differential ability to bear the risks of investing in greenfield assets. For instance, owners of newly created plants need to connect these plants to the electric grid and establish contracts with customers. Given PE's risk bearing capacity (Kaplan and Strömberg, 2009), PE would play the largest role in asset creation, even though a role for PE of driving large-scale asset creation has not been emphasized in prior literature. To the extent that shifting ownership is driven by PE financing of new assets,

[5] Public Utility Commissions (PUCs) will increase a utility's rate base for new construction, and in some cases include credits for Construction Work in Progress (CWIP).

that points to a novel role of PE investors as asset creators.

The first channel for the ownership shift is differences in the financing of new power plants. In line with the latter (Arrow-leaning) hypothesis, we find that PE and foreign corporations are disproportionally financing new greenfield solar, wind, and natural gas plants, while IOUs play a smaller role. Conditional on fuel type (i.e., solar, wind, natural gas, coal, etc.), state, and time, PE is 1.31 percentage points more likely to own a greenfield plant than IOUs, an 80% increase relative to the baseline greenfield share of 1.63%. In models with power plant fixed effects, we observe that the role of PE in creating new assets is even greater, as the results imply that PE is more likely to hold the asset during the greenfield phase and then sell to IOUs afterwards. Overall, the source of financing matters for creating new assets, as not all new ownership types are equally willing to bear the risk. For example, while institutional investors hold a substantial share of the renewable plants, they do not play a large role in the direct financing of greenfield investments, whereas PE and to a lesser extent foreign corporations play a large role. To some extent the role of PE is surprising, as prior literature has emphasized the role of PE in acquiring and restructuring existing assets, not adopting new technology on a large scale with newly created assets.

The second channel by which ownership changes is the sale and acquisition of existing plants. Analyzing IOU-owned plants using a competing risks model, we find that while sales do contribute to the ownership shift from IOUs to PE and the other new ownership types, they do not significantly contribute to leakage. The leakage hypothesis would predict that IOUs will sell the most polluting power plants, specifically older plants and coal plants. We find that older plants owned by IOUs are more likely to be retired than sold. Moreover, IOUs are less likely to sell and more likely to decommission coal plants. The majority of acquisitions in our sample are of relatively newer natural gas plants, where we find operating improvements in analysis below.

The third channel through which ownership can change is differences in decommissioning rates. The competing risks analysis suggests that there is limited leakage of older fossil fuel power plants from IOUs through sales, but it does not address the possibility that IOUs decommission power plants sooner than the new ownership types. Using hazard models, we show that IOUs are more likely to retire plants than foreign corporations, though no significant differences exist with PE. Foreign corporations' lower decommissioning rates suggest they would need to double plant retirements to match IOU and PE behavior, but this translates into only an additional 1.4 plants per year of decommissioning across the entire U.S.

Moving to the second research question, which economic factors contribute to attracting financing from the new modes? We test multiple potential explanations and document strong support for the hypothesis that deregulation is the key factor, as wholesale electricity market deregulation allows the new entrants to sell electricity in an open market. Furthermore, the incumbent IOUs have limited incentives to invest in new technologies, both in their home states and other states, as they wish to protect their assets in place. Even incumbent IOUs that continue to operate in markets that are still regulated will avoid entering and creating assets in new deregulated markets, as they wish to ensure that their rates of return do not increase in ways that lead to regulators limiting their profits.

To test the deregulation hypothesis, we compare the role of incumbent owners, which are primarily IOUs, and new entrants in each of the three channels, as a function of the heterogeneity in local electricity market regulation. The market deregulation measures capture whether the wholesale electricity market is administered by an independent system operator (ISO) as a balancing authority, rather than a traditional vertically integrated utility.[6] We consider two more-restrictive measures of deregulation to capture subtleties in market structure. First, we construct an indicator that reflects only power plants that are in an ISO balancing market and are owned by an independent power producer (IPP), to exclude those that are owned by utilities still subject to rate of return regulation. Second, we consider an ISO restructured measure of deregulation which captures power plants in ISO-balancing markets where electric utilities were additionally restructured through forced divestitures.[7]

We find that the difference in new power plant creation by IOUs versus PE and foreign corporations is robustly significant only in deregulated markets. For instance, IOUs are 1.91 percentage points less likely to own a greenfield plant in deregulated IPP ISO balancing markets, while the difference is economically and statistically insignificant in traditional markets.[8] Adding the regulatory variables to our competing risks model on sales and decommissioning, we find that deregulated markets significantly increase the likelihood of plant sales. Specifically, plants owned by IOUs in deregulated markets are approximately three times as likely to be sold to the new entrants compared to those in traditional markets. Contrary to concerns that deregulation might contribute to leakage, the sales in deregulated areas are concentrated among newer natural gas plants rather than older coal plants. In both traditional and deregulated markets, IOUs tend to decommission older and coal

[6]The introduction of ISOs with a market dispatch mechanism represents an important source of regional variation in competition. In traditional markets, the incumbent utility can potentially exclude new producers from the market by denying transmission access (Fabrizio, Rose, and Wolfram, 2007; Borenstein and Bushnell, 2015; Cicala, 2022).

[7]Around 35.6% of the observations are IPP power plants participating in ISO balancing markets. Approximately 35.0% of the plants in the sample operate in an ISO Restructured market.

[8]Our results therefore do not support the Averch and Johnson (1962) argument that regulated utilities in traditional markets engage in more capital investments because they receive an artificially high rate of return.

plants themselves rather than selling them. Thus, sales in deregulated market are not extending the use of outdated, high-emissions technology, as decommissioning rates do not differ across ownership types conditional on market regulation.

More broadly, deregulated markets accelerate plant decommissioning across all ownership types. Plants in deregulated markets are 40% more likely to be retired than plants in traditional markets. Thus, deregulation not only stimulates new investment and asset transfers but also speeds up the retirement of older, presumably less efficient assets. These findings reinforce that deregulated markets amplify ownership changes through the combined mechanisms of new plant creation, asset transactions, and accelerated shutdowns, with limited evidence of leakage. These trends have changed the dominant ownership type across deregulated markets. For instance, new entrants, including PE, institutional investors, and foreign corporations, accounted for 47% of electricity generation IPP ISO-balancing markets in 2020, versus just 9% in traditional markets. PE has become the main corporate form of power plant ownership in large electricity-generating deregulated states, such as Pennsylvania and Texas.

One concern is reverse causality or that deregulation is driven by anticipation of industry changes or other omitted variables at the local level. However, the ISO-balancing markets were established during the wave of state-level restructurings in the 1990s and early 2000s, so almost exclusively before our sample period and before the expansion of renewable technologies and shale gas. Furthermore, we document that deregulation is unrelated to the state-level potential for renewable energy generation, nor is it related to the amount of natural gas and coal produced by a state. In addition, we address the possibility of omitted variables bias using an instrumental variable (IV) for whether a plant is in a deregulated wholesale market. Our instrument is the difference between the average electricity price in the residential sector and the industrial sector in the plant's state during the 1991–1996 period, established as a determinant of deregulation by White (1996) and Joskow (1997).

Moving to the third research question, the ownership changes we document have implications for the operational performance of power plants. Based on the ratio of fuel consumption to electricity generation (heat rate), fossil fuel plants owned by PE, institutional investors, and foreign corporations operate more efficiently than plants owned by IOUs and consume around 5% less fuel per unit of electricity. The lower heat rate automatically implies reduced carbon emissions and pollution. New entrants improve the efficiency of the acquired power plants as well as create new more efficient power plants. Based on a stacked difference-in-difference analysis, we document that the heat rate of the acquired plants declines by 0.44 in the 24 months after the IOUs sell these plants. Using a matched sample of new power plants, we find that plants created by IOUs have a 0.67 higher heat rate than plants created by new entrants. We also reject an alternative version of the leakage hypothesis, namely that the new owners might operate the fossil fuel assets more intensively. If anything, IOUs operate fossil fuel plants at a higher intensity (capacity factor), particularly in traditional markets.

If economic factors other than deregulation drive the ownership and operational results, they would need to have differential effects on IOUs located in deregulated and traditional markets. We test several alternative hypotheses. First, while there is some support for the idea that IOUs respond less to local climate concerns in asset creation, this factor is not the main driver of the observed differences. Second, we find no support for the hypothesis that differences in sensitivity between IOUs and new entrants to state-level renewable tax incentives and production subsidies explain the results. Third, financial constraints do not explain the patterns, as we find that all types of IOUs, regardless of credit rating, are less likely to create new plants in deregulated markets. Fourth, we find no support for the notion that shareholder activism or ESG ratings explain the ownership changes. If these factors were key, we would expect to observe greater leakage of fossil fuel plants and stronger ownership shifts concentrated in firms facing higher ESG pressures, but we do not. Fifth, we find limited support for the idea that legacy coal assets are holding back IOU investment. IOUs with greater exposure to coal do not exhibit a lower probability of asset creation.

The evidence is most consistent with the hypothesis that deregulation exposes institutional inertia and legacy managerial practices at IOUs. Their historical focus on traditional generation under protected market conditions and fixed rate of return regulation may create information frictions regarding new technologies or agency frictions, such as resistance from existing divisions fearing loss of importance. Internal frictions that apply to the entire sector of IOUs are therefore likely a key reason why deregulation stimulates creation of more efficient plants by new entrants, rather than incentivizing the incumbents themselves to innovate.

In addition to the literature on new entrants as adopters of technology cited above, our findings also relate to research in climate finance (Hong, Karolyi, and Scheinkman, 2020; Giglio, Kelly, and Stroebel, 2021; Darmouni and Zhang, 2024), as we observe that competition and capital from new entrants accelerate the adoption of clean technology. Our results also relate to the literature on the effect of bank financing on emissions and divestment (Green and Vallee, 2022; Sastry, Verner, and Ibanez, 2024; Sachdeva et al., 2024). We show that new entrants do not provide equity financing or strong acquisition demand for older fossil fuel assets, so that IOUs tend to retire these assets, especially in competitive markets.

Our paper connects to the literature on the efficiency gains from deregulation of electricity markets (e.g., Fabrizio, Rose, and Wolfram, 2007; Cicala, 2015, 2022; Jha and Wolak, 2023). Demirer and Karaduman (2023) and Bai and Wu (2023) find that acquired power plants experience efficiency increases. We show that as the regulatory status changes, ownership structure also changes, and new entrants, such as PE and foreign corporations, potentially drive efficiency improvements in the deregulated markets.

Finally, our paper relates to the literature on PE's impact on efficiency and productivity. We study the creation and retirement of assets by PE, rather than focusing only on acquisitions of existing companies (e.g., Kaplan and Strömberg, 2009; Guo, Hotchkiss, and Song, 2011). Creation and destruction require a combination of investors willing to bear risk and market competition, so PE is well-positioned to play a major role in implementing new technologies and shutting down stranded assets. However, these channels are not necessarily fully attributable to PE's business model, since foreign corporations also create new, efficient plants.

2 Data on Power Plants and Electricity Markets

2.1 Power Plant Characteristics

Our sample covers all U.S. power plants reporting to the Energy Information Administration (EIA) over the 2005–2020 period. EIA Form 923 provides data on monthly electricity generation at the power-plant-prime-mover level. That is, if a power plant uses multiple technologies within a given fuel type (e.g., a natural gas plant using a steam turbine and combustion turbine), it will have multiple observations. EIA Form 860 provides information on the power plant characteristics on a generator level. We aggregate the information from EIA Form 860 for power-plant-generators that use the same prime-mover technology and merge both datasets on a power-plant-prime-mover level. Table 1 shows that our sample contains 11,593 power plants and 13,261 power-plant-prime-mover units. Fossil fuel power plants often use multiple prime-mover technologies, while nuclear, hydro, wind, and solar power plants rely only on one prime-mover technology. When we use the term power plant in this paper, we refer to power-plant-prime-mover observations.

Table 1 reports summary statistics on the average power plant characteristics weighted by nameplate capacity. We present weighted statistics as the sample contains many small plants that contribute very little to overall electricity generation.[9] For instance, there are 3,941 solar plants

[9]In the regression estimations, we either use the full sample weighted by capacity or limit attention to the subsample

in the sample, but they account for less than 3% of electricity generation in 2020. The weighted average power plant has a capacity of 0.98GW and is 30.9 years old.

We construct two measures of power plants' operating performance. First, the capacity factor captures operating intensity and is defined as the ratio of electricity generation to monthly capacity (the maximum potential output). Electricity generation is measured as the total electrical output net of the power plant service. Power plants differ in the average capacity factor by fuel type. Nuclear plants operate almost continuously and have the highest capacity factor of 0.86, while solar plants depend on the sun hours and have the lowest capacity factor of 0.24. Second, the heat rate captures operating efficiency and is defined as the ratio of fuel consumption in millions of Btu to electricity generation in MWh. The heat rate can be measured for fossil fuel and nuclear plants, and lower values imply lower fuel consumption and higher efficiency.

During our sample period, the electricity industry exhibited substantial construction of new plants and decommissioning of old plants. Out of 13,261 unique plants, 6,082 are new greenfield plants, and their first 12 months of operation account for 1.63% of the sample on a capacity-weighted basis. Greenfield plants use either solar and wind energy or natural gas. During this period, 1,949 power plants were shut down, and their last 12 months of operation account for 1.03% of the sample. Decommissioned plants are concentrated in fossil fuels, such as coal and natural gas.

2.2 Power Plant Ownership

We manually collect ownership data based on regulatory announcements, Preqin dataset, S&P Global, and newswire articles, and classify the power plant owners into eight categories.[10] The largest category based on ownership stakes is *domestic public investor-owned utilities* (IOUs), which covers U.S. publicly listed corporations whose primary business is to provide electricity and other utility services. This category includes both traditional utilities and independent power producers (e.g., Duke Energy, Exelon, PG&E, Southern Company, etc.). The *IOUs* category also includes YieldCo companies, such as NRG Yield and NextEra Energy, that are majority-owned by U.S. corporations. *IOUs* are the incumbent owners of power plants as the vast majority originated from vertically-integrated electric utilities.

The other traditional owners of power plants are industrial firms, government, and cooperatives.

of plants with a capacity of at least 20MW. In Online Appendix Table A.1, we report summary statistics without weighting the power plants, using only the subsample of power plants with a capacity of at least 20MW.

[10]We do not classify tax equity investors as owners because tax equity investors do not have decision-making power and acquire different share classes (Garrett and Shive, 2022).

Industrial companies engaged in energy-intensive manufacturing, such as paper, steel, and aluminum, often own power plants (e.g., International Paper Co, Dow Chemical Co, and Alcoa Corporation). These industrial firms consume most of the produced energy for their own factories. The *government* category includes plants owned by federal, state, and local government entities (e.g., Tennessee Valley Authority and U.S. Bureau of Reclamation). The electric *cooperatives* category covers plants that are built and owned by the communities they serve (e.g., Basin Electric Power Coop and Associated Electric Coop).

The new rising owners of power plants are private equity, institutional investors, and foreign corporations. *Private equity (PE)* includes investments made by PE buyout and infrastructure funds as well as other investment vehicles (e.g., ArcLight, LS Power, and Macquarie). This category also includes a small number of plants owned by private firms (e.g., Caithness Energy, Koch Industries, and Tenaska). *Institutional investors* covers direct investments by pension funds, insurance companies, and sovereign wealth funds in power plants. Almost all direct investments come from foreign institutions, such as Canadian and Dutch pension funds (e.g., CPPIB, OMERS, and APG). The *foreign publicly listed corporations* category covers power plants owned by European, Canadian, and Asian energy companies (e.g., EDP Group, Engie, ITOCHU, and Osaka Gas). The final category is *other* small power plants, which we have not classified in one of the seven categories.

Figure 1 shows that we categorize 99% of electricity generation in any month over the 2005–2020 period into one of the seven ownership categories. If a power plant is owned by multiple ownership types, we divide the ownership stake equally across the ownership types (i.e., if a PE and institutional investor jointly own a power plant, we assume that each ownership type owns 50% of the plant).[11] This adjustment does not matter for most ownership types, as they typically act as sole investors and acquire 100% stake in the power plants. Institutional investors are the exception, they often co-invest with other investors and share ownership in 87% of their observations.[12]

In Figure 1, we observe that the percentage of electricity generated by power plants owned by IOUs declines from 70% in 2005 to 54% in 2020. PE, institutional investors, and foreign corporations replace domestic IOUs as their share jointly increases from 7% in 2005 to 24% in 2020. The generation share of governments, cooperatives, and industrial firms remains constant. The ownership

[11] EIA Form 860 provides some information on ownership shares for power plants, but it also does not distinguish within joint ventures. For example, after the buyout, Calpine Corp will be listed as the owner without distinguishing the shares of Energy Capital Partners and Canada Pension Plan Investment Board.

[12] For instance, Canada Pension Plan Investment Board co-invested with Energy Capital Partners PE fund in the buyout of Calpine Corporation in 2018. Alberta Investment Management Corporation established a joint venture with AES Corporation to acquire Sustainable Power Group LLC in 2017.

shifts while the total electricity production, exports, and imports remain constant. Online Appendix Figure A.1 shows that the U.S. produced around 4.1 trillion kWh of electricity in 2005 and the total output has remained constant over our sample period. The total imports and exports of electricity also remain stable and account for less than 1.5% of the U.S. market.

The ownership structure of power plants differs across fuel types.[13] Figure 2 shows that, over the 2005–2020 period, natural gas became the main fuel and replaced declining coal generation. Wind and solar energy are increasing and account for the majority of newly created plants. The amount of electricity generation from hydro and nuclear plants stays relatively stable and their ownership structure also does not exhibit significant shifts. The new ownership types (PE, institutional investors, and foreign corporations) controlled 34% of the natural gas, 58% of the wind, and 47% of the solar electricity generation as of 2020. IOUs are especially negatively affected by the declining coal generation.

2.3 Regulation of Electricity Markets

ISO Balancing is our broadest measure of market deregulation, and it is an indicator for power plants that operate in a wholesale market administered by an Independent System Operator (ISO) as a balancing authority. The ISOs were formed after the adoption of the Energy Policy Act of 1992 and Federal Energy Regulatory Commission orders 888 and 889 of 1996 to open the wholesale electricity markets to competition. We classify the following balancing authorities as ISOs: California ISO, Electric Reliability Council of Texas, Midcontinent ISO, ISO New England, New York ISO, PJM Interconnection, and Southwest Power Pool. The ISOs took over the control of the transmission system from the local utility and conduct auctions to provide non-discriminatory grid access. In the areas that are not serviced by an ISO, vertically integrated local utilities own power plants generating electricity as well as the transmission system and delivery network. These utilities do not adopt a market dispatch mechanism and could potentially exclude independent producers from the market by denying transmission access (Borenstein and Bushnell, 2015; Cicala, 2022). The vertically integrated utilities are typically owned by IOUs or the government.

The advantage of *ISO Balancing* measure is that it covers all plants bidding into an ISO wholesale market, but many of these plants are still subject to rate-of-return regulation, especially in MISO and

[13] The hydro category includes only plants using hydraulic turbines, while plants with pumped storage have a separate category. The solar category includes only plants with a photovoltaic prime mover, while plants with steam turbines that can use a solar stream are a separate category. The EIA data covers only utility-scale solar and does not include information on distributed small-scale solar. The capacity of the small-scale solar installations is 50% of the capacity of utility-scale solar, so the EIA data underestimates the importance of solar energy (EIA Table 4.3).

SPP. Thus, this measure includes also unrestructured plants that operate in a competitive market. *IPP ISO Balancing* is our main measure of market deregulation, and it captures only power plants that participate in an ISO Balancing market and are owned by an independent power producer (IPP). This measure captures only IPPs that operate under a market-based pricing model and excludes all plants owned by regulated utilities that operate under a cost-of-service model (Borenstein and Bushnell, 2015).

ISO Restructured is an alternative more restrictive definition of market deregulation. It captures power plants that participate in an ISO wholesale market and are located in areas with restructured utilities.[14] States that have an ISO restructured market required vertically integrated utilities to break up through asset sales. In these cases of forced divestiture, the utilities sold off their power plants or transferred them to unregulated affiliates (Fabrizio, Rose, and Wolfram, 2007; Cicala, 2015). The forced divestitures were completed by 2002, so they did not drive the ownership changes in our sample period, but these measures created more competitive markets. In addition, the initiatives to restructure electricity markets stopped after the California electricity crisis in 2000–2001.[15]

All three deregulation measures are defined on a power-plant-level, not on a state-level (similar to Cicala, 2022; Jha, 2023). Based on Table 1 Panel D, 61% of the power plants participate in a wholesale market administered by an ISO balancing authority, while only 36% are IPPs in an ISO balancing market. The *ISO Restructured* measure applies to 35% of the plants. The overlap between the *IPP ISO Balancing* and *ISO Restructured* measures is substantial, as 27% of plants in the sample are classified as deregulated under both measures. Online Appendix Table A.2 shows how many plants in each state operate in a deregulated market. In our analysis, to further bolster the causal interpretation, we use the difference between the average electricity price in the residential sector and the industrial sector as an instrumental variable. We measure the price difference *ResidIndPD* on a state level over the 1991–1996 period and use it to instrument *ISO Restructured* markets. The data on average state prices comes from the EIA State Energy Data System (SEDS). Table 1 shows that the average price difference is $9.78 with a standard deviation of 2.99.[16]

In addition to the market regulation, we also control for climate concerns and renewable energy

[14] *ISO Restructured* classifies mainly the following balancing authorities as restructured markets: Electric Reliability Council of Texas, ISO New England, New York ISO, and PJM Interconnection.

[15] An alternative measure of the regulatory environment captures areas with restructured retail electricity markets, i.e. selling power to end-use customers (Borenstein and Bushnell, 2015). The vast majority of power plants located in an area with retail choice participate in an *ISO Restructured* wholesale market.

[16] In Online Appendix Table A.3, we show that state-level natural resources, economic, and political factors do not predict electricity market deregulation. The decision to deregulate markets is unrelated to variation in state-level solar and wind energy potential, nor is it related to the production of natural gas or coal in a state normalized by the amount of electricity consumption.

policy incentives on a state level. The climate concern measure is based on the Yale Climate Opinion Survey (Howe et al., 2015) which was created in 2014 and then rerun in 2016, 2018, and 2021.[17] The comparison of responses within a state over time is limited by changes in the survey design, but we use it to control for cross-sectional differences across states in the same year. Our *Climate Concern* variable is based on the percentage of the state population who think that global warming is happening and is defined as the percentile ranking of the state where the plant is located. The percentile rankings of states over time are very stable, so we merge the survey ranking in 2014 with our data on power plants over the 2005–2014 period. We make similar adjustments with the later survey waves.

We use the Database of State Incentives for Renewables & Efficiency to collect data on the policy incentives introduced by different states to stimulate renewable energy. We split the renewable policy initiatives into three types of tax incentives: Corporate Tax, Property Tax, and Sales Tax; and two types of production incentives: Production Quantity and Tariffs.[18] Our analysis uses primarily a *Renewables Incentives* index, which aggregates the three tax indicators and the two production indicators. Online Appendix Table A.5 presents the average value of the five indicators and aggregate renewables incentives index by state. The index varies from 0.00 in Arkansas to 3.91 incentive types in Vermont.

3 The Channels of Ownership Changes

As domestic public IOUs (which we will refer to as simply IOUs) ownership share declined from 70% in 2005 to 54% in 2020, PE, institutional investors, and foreign corporations have gradually replaced IOUs as power plant owners. These ownership changes can occur through three channels: creating new plants, selling existing plants, and decommissioning plants. In this section, we examine the relative importance of the three channels for the ownership changes, so as to shed light on the reasons for the rise of the new ownership types. Based on prior literature, one would expect any shift to the new ownership types to be driven by the sales and decommissioning channels, while the creation channel (i.e. creating new assets by PE) would have a limited contribution, for three

[17]The Yale Climate Opinion Maps data has been used by Bernstein, Gustafson, and Lewis (2019) and Baldauf, Garlappi, and Yannelis (2020) to examine the relation between climate change beliefs and real estate prices.

[18]Corporate tax incentives capture programs that provide a corporate tax credit, corporate tax deduction, and corporate depreciation. Property tax incentives offer property tax exemption or reduction. Sales tax incentives offer an exemption or reduction from sales and use tax for equipment, generation, etc. Renewables production incentives offer compensation per KWh that can differ by fuel type and plant capacity. Renewable tariffs capture primarily feed-in tariffs, which offer long-term contracts with an above-market price to renewable energy producers.

reasons.

First, PE firms are generally known for acquiring and restructuring existing assets (e.g., Kaplan and Strömberg, 2009), rather than for adopting new technology on a large scale with newly created assets. The selling mechanism has received significant attention in prior research on cross-border mergers and acquisitions (Erel, Jang, and Weisbach, 2022), and PE buyouts (Bernstein, 2022). PE then specializes in restructuring assets and bringing operational improvements (e.g., Guo, Hotchkiss, and Song, 2011, Davis et al., 2014 Gompers, Kaplan, and Mukharlyamov, 2016; Howell, Jang, Kim, and Weisbach, 2022). Institutional investors could also contribute to the sales channel as co-investors in large buyouts (Fang, Ivashina, and Lerner, 2015; Lerner, Mao, Schoar, and Zhang, 2022).

Second, incumbent IOUs face stricter disclosure rules and more public pressure, giving them incentives to transfer older and more polluting plants to owners with more lenient regulatory and disclosure requirements, such as PE and foreign corporations (Fowlie et al., 2016; Benthem et al., 2022; Bolton and Kacperczyk, 2022; Duchin et al., 2024; Bernstein, 2022). This leakage argument predicts that, in addition to sales, differences in decommissioning rates across the financing modes would explain the shifting ownership as the new owners operate their power plants for a longer period of time, particularly for legacy technologies.

Third, a Schumpeter-leaning argument is that domestic IOUs, which are the traditional incumbent owners in our setting, have competitive advantages for creating assets. Their advantages are size, synergies with existing operations, access to the transmission network, and ability to impact government policy. In addition, regulated incumbent utilities generally receive compensation through the rate base for the fixed costs of building new assets (Averch and Johnson, 1962; Joskow and Schmalensee, 1986; Joskow, Rose, and Wolfram, 1996), which incentivizes them to build more assets.[19] This argument predicts that the creation channel does not drive the ownership changes as IOUs have advantages and incentives to create new greenfield assets.

However, an alternative hypothesis is that the creation channel could drive the ownership shift, as the new owners have stronger incentives to adopt new technologies. This is indeed what we find, despite the above arguments. IOUs may prefer to delay the adoption of new technology (Arrow, 1962), especially under the protection of market power (Bertrand and Mullainathan, 2003; Cunningham, Ederer, and Ma, 2021). Under this argument, new entrants will be more likely to own new power plants. In addition, the new entrants generally do not have an existing stake in the

[19] Public Utility Commissions (PUCs) will increase a utility's rate base for new construction, and in some cases include credits for Construction Work in Progress (CWIP).

market, which improves their incentives to expand utilizing new technologies. However, creating plants is risky as the owners need to connect the new plants to the electric grid and establish sales contracts, so we do not expect that all new financing modes equally contribute to the creation channel. This argument requires a combination of a low stake in the market and a high risk-bearing capacity. Among the new entrants, PE especially could play a larger role in creating greenfield plants due to its high-powered incentives and risk-bearing capacity (Jensen, 1989; Kaplan and Strömberg, 2009), while institutional investors prefer to own directly stable assets and would have a limited role in directly financing the creation of assets (Andonov, Kräussl, and Rauh, 2021).

3.1 Creating New Greenfield Power Plants

Our dataset does not provide information on all potential entries, so we cannot estimate the probability of completing a proposed power plant. We estimate the differences in capacity-weighted conditional probabilities of owning a greenfield plant across ownership types relative to their baseline ownership stakes while controlling for fuel type, location, and regulation. In Table 2, we estimate the following specification, where the unit of observation is at the plant-prime-mover-month level:

$$Greenfield_{i,t} = \beta_1 IOU_{i,t} + \gamma' Z_{i,t} + \delta_{fst} + \varepsilon_{i,t}. \quad (1)$$

The dependent variable $Greenfield_{i,t}$ is binary and equals one for the first 12 months of plant i operation. We measure the ownership of plant i in month t by domestic IOUs, while the omitted categories are PE, institutional investors, and foreign corporations. In the OLS regressions, we weight the power plants by nameplate capacity. The weighting enables us to estimate economically more representative results as the new renewable plants tend to have a smaller capacity: for example, 3,630 solar plants were created during our sample period, but they accounted for less than 3% of electricity generation in 2020. Our results are robust to using logit specifications instead of OLS, without weighting the observations.[20]

To distinguish differential propensities of ownership types to create assets from what could be differential preference to invest in certain fuel types (e.g., renewable energy), we interact several fixed effects. The 19 fuel-type fixed effects capture the baseline greenfield incidence of a power plant of a given fuel-type (e.g. solar or natural gas), while state fixed effects capture differences in weather conditions or available natural resources affecting plant location. We saturate the specifications by

[20]OLS regressions are also more suitable for our setting than nonlinear logit regressions as our focus is on the marginal effects rather than the latent index variable (Angrist and Pischke, 2009; Bertrand et al., 2007).

including δ_{fst}, fully interacted fuel-type, state, and time (year-month) fixed effects. When including this saturated set of fixed effects, the estimates rely only on variation in owner type and probability of owning greenfield assets across power plants using the same fuel, located in the same state, and at the same moment of time.

We extend the analysis by estimating a model with power plant fixed effects p_i:

$$Greenfield_{i,t} = \beta_1 IOU_{i,t} + \gamma' Z_{i,t} + p_i + \delta_{fst} + \varepsilon_{i,t}. \tag{2}$$

In these specifications, the relation between ownership type and creation of plants is identified using only variation within power plants that are both in the greenfield stage during the sample period and change ownership during the sample period. Essentially these specifications inform us whether some financing modes are more likely to own a given plant during the greenfield stage and sell it later to other financing modes.

The specifications with power plant fixed effects also address the possibility that different propensities to create assets across ownership types simply reflect different trends across ownership types. In our analysis, power plants are considered greenfield only in the first 12 months and later can have multiple observations that are not classified as new assets. This definition implies that owners who create plants at the end of the sample period can appear to be investing relatively more in greenfield compared to owners who create more plants earlier. This could potentially bias the estimates if the owners do not create plants in a balanced way over the entire sample period. However, this bias does not affect the specifications with power plant fixed effects because we are estimating the coefficients using only variation within a power plant rather than comparing power plants created at different moments of time.

In Column (1) of Table 2, we find that domestic IOUs have a 0.99 percentage point lower probability of owning a greenfield plant than the omitted ownership types, which are the new entrants: PE, institutional investors, and foreign corporations.[21] This coefficient corresponds to a 61% decrease relative to the baseline unconditional probability of 1.63% to own a greenfield power plant in any given month. Column (2) shows that this effect remains significant and is even stronger when we include power plant fixed effects.

Figure 3 Panel A shows that not all new entrants are equally likely to create greenfield plants. Specifically, PE has a disproportionally higher probability of owning a greenfield power plant. Based

[21] In the analysis, we always control but do not report the coefficients on government, cooperatives, and industrial firms. These ownership structures are generally less likely to create new power plants.

on Panel A, PE has a 2.38 percentage points higher probability of owning a greenfield power plant, while institutional investors and foreign corporations do not differ significantly from IOUs. This result confirms that being a new entrant with a low stake in the market is insufficient to engage in asset creation. An additional requirement is to have a higher risk-baring capacity, such as a PE organizational structure. The specifications with power plant fixed effects further highlight the role of PE. For a given plant that was created and changed ownership during the sample period, PE is the only ownership type that is more likely to create and sell the plant. Thus, the aggregate statistics on shifting ownership underestimate to some extent the role that PE plays in the electricity industry as PE creates more new assets that move to different owners during their lifespan.

Next, we decompose the creation results across fuel types, focusing on the ownership of solar, wind, and natural gas plants as they account for the vast majority of newly created power plants.[22] The baseline probability for greenfield solar and wind plants is 13.66%, which is relatively high as these new technologies were not adopted before our sample period and almost all solar and wind plants have 12 months of greenfield stage. The baseline probability for greenfield natural gas plants is 1.47% which is lower as they are added to an already existing capacity of natural gas plants. However, in terms of total created capacity, the new renewable and natural gas plants are equally important, as the natural gas plants are larger.

In Columns (3)–(6) of Table 2, we find that IOUs are significantly less likely to own new renewable as well as new natural gas plants. The coefficient magnitude is higher for solar and wind plants, but these estimates reflect the higher baseline probability. Figure 3 Panels B and C show that these results are driven by PE, as PE is consistently more likely to own greenfield plants across all fuel types. For instance, based on the models without power plant fixed effects, PE has a 6.43 and 0.71 percentage points higher probability of owning greenfield renewable and natural gas plants, respectively. The main difference across fuel types is the role of foreign corporations. We observe that foreign corporations are more likely than IOUs to own greenfield solar and wind power plants, but they display a similar probability of owning greenfield natural gas plants.

For institutional investors, we find that they do not have a higher probability of owning greenfield power plants after controlling for interacted fixed effects, even though Figure 2 shows that they own a substantial share of the wind and solar power plants. This result aligns with the argument that the ownership type of the new entrants matters for the creation channel. Institutional investors

[22] Some natural gas power plants also use biogenic municipal solid waste, landfill gas, wood waste, or other gases as alternative fuels, so we can still include fuel-state-time fixed effects in the specifications.

prefer to co-invest in established operational renewable plants and provide large amounts of capital to other investors for sales or partial exit, but do not directly play a large role in creation.

In Online Appendix Table A.6, we show that our results are robust to using logit specifications instead of OLS. Moreover, in Online Appendix Table A.7 , we document that the results are not driven by a few large newly-created plants by presenting unweighted specifications.[23]

3.2 Selling and Decommissioning Power Plants

In this section, we jointly consider the second and third channels of ownership transition: selling and decommissioning power plants. Financial press and industry reports have suggested that IOUs may be selling older polluting plants to the new ownership types, particularly PE.[24] Sales from listed corporations to private owners have been documented when analyzing polluting industrial plants (Shive and Forster, 2020; Duchin, Gao, and Xu, 2024). If that practice is dominant in the electricity industry, the shift in the financing of electricity generation to PE that we document might be thought of as driven by a desire to extend the life of old, polluting assets. To the extent that these new owners are subject to more lenient regulation and weaker reporting requirements, this "leakage hypothesis" predicts that they would acquire, continue operating, and postpone the decommissioning of older fossil fuel plants.

In Table 3, we estimate a competing risks model and compare the characteristics of power plants that are sold and retired by domestic IOUs. For each power plant i owned by IOUs, we observe the time to exit t_i and the exiting cause c, where c_1 is selling and c_2 is decommissioning. For each cause, there is a latent duration T_c, which is the time elapsed before the plant operation ends via exit cause c in the absence of any other causes. However, other competing causes may end plant operation before this time. Thus, the actual exit time and exit cause can be interpreted as the realizations of variables T and C, which are defined as $T = min(T_c, c = 1, 2)$ and $C = argmin_c(T_c, c = 1, 2)$. At each point in time, the hazard function for risk c is:

$$h_c(t) = \lim_{\Delta t \to 0} \frac{Pr(t \leq T_c \leq t + \Delta t | T_c \geq t)}{\Delta t}. \quad (3)$$

[23] Specifically, we analyze the subsample of plants with a capacity above 20MW. The unconditional baseline probability in the unweighted sample equals 2.77%, which is higher than 1.63% in the weighted sample because the newly created plants tend to be smaller than the existing plants. The results confirm that domestic IOUs are less likely to own new power plants than PE and foreign corporations, and the differences are even larger in the unweighted sample.

[24] See for example the Private Equity Stakeholder Project report "Private Equity Propels the Climate Crisis: The Risks of a Shadowy Industry's Massive Exposure to Oil, Gas and Coal" and the New York Times article "Private Equity Funds, Sensing Profit in Tumult, Are Propping Up Oil."

The overall hazard function is $h(t) = \sum_{c=1}^{2} h_c(t)$ where h_1 and h_2 are the cause-specific hazard rates for selling and decommissioning. The cause-specific hazard functions are

$$h_c(t, X) = h_{0c}(t) exp(\beta_c X_{i,c,t}), \tag{4}$$

where h_{0c} is the baseline hazard function for exit cause type c at time t, and $X_{i,c,t}$ is a vector of covariates for power plant i specific to hazard c at time t. The proportional hazard model allows the effects of the covariates to differ by exit cause type. In the specifications, we include two main proxies of power plants that are potentially subject to leakage. First, *Plant Age* captures older power plants that use legacy technologies. Second, the *Coal* fuel type indicator covers power plants that use coal and have higher emissions than the other technologies.

Table 3 reports the hazard ratios of the competing risks model. In Columns (1) and (2), the main event is a power plant sale, while the competing event is a plant decommissioning. In Columns (6) and (7), the main event is plant decommissioning, while the competing event is a sale. The results broadly do not support the leakage hypothesis. First, focusing on the coal coefficient, IOUs are less likely to sell and more likely to decommission coal power plants, which are the most polluting plants of the six main fuel types.[25] For instance, based on Column (6), IOUs are 79.4% more likely to decommission a coal plant than a natural gas plant. Second, IOUs are much more likely to decommission an older power plant than a younger one, by a factor of five to one for every unit increase in log age.

In Columns (3) to (6), we decompose the sales exiting cause into subcauses by ownership type of the acquirer: PE, institutional investors, foreign corporations, and others (unreported in the table, but included as a competing risk). These results provide more mixed evidence on the leakage hypothesis. One the one hand, the magnitude on the log age coefficients remains close to one, which suggests that all ownership types do not acquire old power plants. On the other hand, the coefficients on coal plants vary significantly between ownership types, from 0.12 for institutional investors to 0.66 for foreign corporations. Foreign corporations seem to have a higher probability of acquiring coal plants and not statistically different from acquiring natural gas plants. The results show that the financing mode matters for the extent of leakage. However, PE — the largest new ownership type of power plants that has drawn the most concern — does not appear to play a major role in leakage through acquisitions.

[25]In the specifications, we control for all 19 fuel types that are part of the EIA classifications but display the coefficients only for coal, nuclear, hydro, wind, and solar power plants (the omitted category is natural gas plants).

In the analysis in Table 3, we define the events of interest based on the final outcome in the dataset. For a small number of power plants, we observe multiple outcomes, such as a plant first being sold by an IOU to a PE firm, later sold back to an IOU, and finally decommissioned by an IOU. In Online Appendix Table A.8, we show that our results and conclusions are robust to defining the events of interest based on the first outcome instead of the last outcome during the sample period. This robustness test by design has fewer decommissioning events and more sales events, but our results on the relation between sales and the two leakage proxies remain the same.

Overall, the sales channel is highly relevant, as IOUs have sold 656 out of 2,767 larger plants they owned, but it explains only part of the ownership transitions and does not have a substantial effect on plants using new renewable technologies or coal plants using older technologies. While in other industries transactions account for the vast majority of ownership changes and privatization reforms (e.g., La Porta and López-de Silanes, 1999; Dinc and Gupta, 2011; Shive and Forster, 2020; Bellon, 2022; Howell, Jang, Kim, and Weisbach, 2022; Duchin, Gao, and Xu, 2024), creation of new power plants as well as decommissioning of older plants are highly relevant in the energy sector.

The competing risks analysis suggests that there is limited leakage of older fossil fuel power plants from domestic IOUs through sales, but it does not address the possibility that IOUs decommission power plants sooner than PE, institutional investors, and foreign corporations because they are subject to stricter disclosure requirements and public scrutiny. In Table 4, we estimate the differences in the likelihood of power plant decommissioning across ownership types using a Cox proportional hazard model:

$$h(t) = h_0(t)exp(\beta_1 IOU_{i,t} + \gamma' Z_{i,t} + \delta_s + \lambda_f). \tag{5}$$

The hazard event of interest is a complete decommissioning of power plant i in month t, not a partial retirement of one generator. To exclude the effects of a large number of smaller plants on the results, we estimate this specification only on plants with a capacity of at least 20MW, although as robustness in Online Appendix Table A.9 we conduct an OLS analysis on the full sample with observations weighted by capacity. The specifications include $Z_{i,t}$ controls for plant age and capacity, as larger plants have greater strategic importance for network stability and security of electricity supply. We also control for λ_f fuel and δ_s state fixed effects.[26] In these specifications, the ownership coefficients can be interpreted as differences in the hazard rate of decommissioning a plant, controlling for differences in profitability and efficiency of different fuels and technologies

[26]The Cox proportional hazard model implicitly accounts for time fixed effects, as it is robust to any baseline hazard function. This feature of Cox proportional hazard models makes it robust to time-specific common factors.

as well as plant capacity and age, with coefficients greater than one reflecting an increased hazard relative to the baseline.

Columns (1) and (2) of Table 4 show that IOUs are more likely to retire power plants than institutional investors and foreign corporations, which is consistent with the leakage hypothesis. There is no difference with PE so the largest and most controversial form of new ownership does not contribute to the leakage of older fossil fuel power plants. The main leakage effect is relative to foreign corporations. For instance, the coefficient of 0.51 implies that foreign corporations need to double the number of retired plants to reach the decommissioning rate of IOUs and PE, which translates into 23 additional decommissioned fossil fuel plants during our sample period or 1.43 plants per year. Institutional investors do almost no retiring of plants, but they also have a very limited baseline exposure to power plants using coal, which is the main fuel type subject to shutdowns. Consistent with our findings on greenfield assets, institutional investors appear to seek stable operating assets and do not want to hold power plants either during the greenfield stage or during the decommissioning stage.[27]

In Columns (3)-(6) of Table 4, we examine whether the decommissioning rates across ownership types differ by fuel type. The analysis focuses on coal and natural gas plants, which account for the vast majority of shutdown plants.[28] In line with the leakage hypothesis, the differences in decommissioning rates seem to be concentrated among coal power plants as domestic IOUs shut down coal plants faster. The aggregate significant difference in decommissioning rates between IOUs and foreign corporations appears to be driven by both coal and natural gas plants. The decommissioning rates of PE relative to IOUs vary across fuel types: PE seems less likely to retire coal and petroleum plants, but more likely to retire natural gas plants. However, these coefficients are statistically insignificant so the evidence is not as conclusive as in the greenfield analysis.

In Online Appendix Table A.9, we provide robustness analysis using OLS, defining a dependent variable that equals one for the last 12 months of the plant's operation. These specifications allow for weighting the observations by plant capacity and include fully interacted fuel-type, state, and year-month fixed effects. In line with the hazard results, PE has a similar probability of retiring

[27]When investing directly in power plants, institutional investors seem to reduce their exposure to the creation of new assets as well as shut down of old assets, potentially because these activities are associated with higher liability and litigation risks (e.g., Bellon, 2022). Consequently, we find that institutional investors do not hold almost any plants in the decommissioning stage but have also very limited overall exposure to coal power plants. Column 4 of Table 4 shows that the coefficient on institutional investors cannot even be estimated in the subsample analysis of coal plants because they have very low ownership of coal plants.

[28]If a power plant is designed to use both coal and natural gas as a fuel, we classify this plant in the sample of coal and petroleum power plants.

a plant as IOUs, while institutional investors and foreign corporations have a significantly lower probability of decommissioning a plant. In models with power plant fixed effects, we observe weaker statistical significance as few older fossil fuel plants change ownership, but foreign corporations seem to have lower decommissioning rates.

Overall, we document that the shifting ownership is driven by two channels, the creation and acquisitions of plants by the new owners, while the decommissioning channel has a more nuanced role. Especially PE firms are more likely to create new power plants and their willingness to finance the capital expenditures to adopt new innovative technologies contributes significantly to the shifting ownership structure.

4 Ownership Changes and Market Deregulation

In this section, we examine which economic factors contribute to attracting financing from the new modes (PE, institutional investors, and foreign corporations). We test multiple potential explanations and document strong support for the hypothesis that electricity market deregulation is the key factor that stimulates the ownership changes from IOUs to new entrants. The role of market deregulation in attracting capital is robust to other potential explanations, such as climate concerns and preferences among the local population, policy incentives for renewable energy, and constraints of IOUs.

The analysis of the relation between ownership changes and market deregulation broadly addresses the following theoretically-motivated question. Is the regulation that protects the markets and pricing for incumbents positively (under the Schumpeter view) or negatively (under the Arrow view) related to capital investments in electricity generation, both for renewables and fossil fuels? Following the Arrow view, we hypothesize that market deregulation incentivizes new entrants to create and acquire power plants for three reasons.

First, market regulation affects the ability of a power plant to operate and sell electricity. Deregulated markets may attract more capital from new entrants as production allocation occurs through a market mechanism and is not controlled by a monopolist utility that is also involved in electricity generation.

Second, incumbent utilities in deregulated markets have substantial assets in place and weaker incentives to invest in creating new greenfield assets, as they wish to protect assets in place. In addition, these utilities were protected for a long time from market mechanisms and may be operating the existing assets less efficiently. This argument could potentially provide a particularly strong incentive for PE entry, but less so for institutional investors who have limited restructuring and operational expertise. IOUs protected for a long period of time from market mechanisms may have less productive management cultures that originated from monopolistic utilities, as management practices have been shown to be less efficient when product market competition is weak (Bloom and Van Reenen, 2007). In this sense, even spin-offs from incumbent IOUs may not be effective at creating or restructuring assets.

Third, incumbent IOUs in the remaining traditionally regulated markets are still subject to rate of return regulation. As a result, we hypothesize that they have limited incentives to invest in new technologies, both in their home-regulated markets and other deregulated markets. Whether investing in home-regulated markets, or in other areas that are deregulated, incumbent IOUs in regulated markets would prefer to ensure that their capital expenditures, cash flows, and profitability do not lead them to exceed their fixed rate of return approved by the regulator (Joskow and Schmalensee, 1986).

We consider several alternative hypotheses. First, states whose populations are highly concerned about the climate could attract new investors. Second, states implement incentivizes for investment in renewable technologies. Third, shareholder activism around ESG or credit constraints arising from the pooling of new technologies with legacy technologies could reduce IOUs investment relative to investment by new entrants, especially PE. If these alternative factors were strongly operative and correlated with deregulation, our results on deregulation in fact reflected these other factors. However, we at best find mixed evidence of these factors, and they do not reduce the measured impact of deregulation.

4.1 Creating New Greenfield Power Plants and Market Deregulation

To study the extent to which market regulation affects asset creation, we use several measures of market deregulation. $ISO_{i,t}$ indicates whether a power plant i operates in month t in a deregulated market. We are primarily interested in the coefficients on the interaction terms between the ownership types and market deregulation indicators (e.g., $IOU_{i,t} \times ISO_{i,t}$), which examine whether market deregulation has a differential impact on the ownership types:

$$Greenfield_{i,t} = \beta_1 IOU_{i,t} + \beta_2 ISO_{i,t} + \beta_3 IOU_{i,t} \times ISO_{i,t} + \gamma' Z_{i,t} + \delta_{fst} + \varepsilon_{i,t}. \tag{6}$$

We can include the $ISO_{i,t}$ deregulation measures together with the δ_{fst} fully interacted fuel-type, state, and time fixed effects because the electricity market regulation varies within some states (e.g., Texas and California). Still, the baseline effect of deregulation on asset creation, which seems to be positive, will be mostly absorbed by the saturated fixed effects.[29]

The market deregulation hypothesis predicts that the estimated gap in creating new power plants between IOUs and PE will be concentrated in deregulated markets, and this is indeed what we find. Using the broadest *ISO Balancing* definition of market deregulation in Column (1) of Table 5, we find that the interaction term of IOUs and *ISO Balancing* is negative and significant, while the baseline coefficient on IOUs is insignificant. IOUs are 1.16 percentage points less likely to own a greenfield plant in deregulated markets, but they are equally likely to own a greenfield plant in traditional markets.

Figure 4 Panel A confirms that PE creates more power plants than IOUs, and the difference is significant only in deregulated markets. For instance, in ISO balancing markets, PE is 1.88 percentage points more likely to own a greenfield plant. Foreign corporations are also more likely to create new plants in deregulated markets. The difference is not as large as for PE, but it is robustly significant across all definitions of deregulated markets. The coefficients on institutional investors remain statistically and economically insignificant.

To sharpen the estimation of the market deregulation effect on the creation channel, we extend the analysis using a more restrictive ISO measure. One limitation of the *ISO Balancing* measure is that it would include plants that are subject to rate-of-return regulation but operating in deregulated markets. In our setting, IOUs operate both as regulated electric utilities as well as independent power producers (IPPs), while new entrants operate predominantly as IPPs.[30] To address this discrepancy, our preferred measure of market deregulation examines only power plants owned by IPPs in ISO balancing markets. If the differences between IOUs and new entrants reflect only the differences in the probability of owning greenfield plants between regulated electric utilities and IPPs, we would expect that the baseline coefficient on *IPP ISO Balancing* should be positive and significant, while the interaction term of IOUs × *IPP ISO Balancing* should not be significant.

However, in Column (2) of Table 5, we effectively find the opposite, suggesting that differences

[29] Online Appendix Figure A.2 Panel A shows that deregulated markets attract more capital to adopt new technologies. At the end of 2020, greenfield plants created during our sample period represent 36% of the total installed capacity owned by IPPs in ISO balancing markets and 20% in traditional markets. Panel B shows that this difference is concentrated in renewable power plants. Newly created solar and wind plants represent 22% of the installed capacity in IPP ISO balancing markets and only 7% in traditional markets, and the difference is increasing over time.

[30] The IOU category includes both traditional utilities and IPPs. These IPPs emerged from the assets of legacy IOUs that were restructured in deregulated markets. The IOU category also includes yieldcos, which are spun off from the traditional entities. The new entrants can also operate as regulated utilities if they acquire a regulated IOU.

between domestic IOUs and new entrants do not reflect merely differences between regulated utilities and IPPs. We document that, within the universe of deregulated IPPs operating in ISO markets, IOUs are 1.91 percentage points less likely to own a greenfield plant.[31] Figure 4 Panel A shows that as we move towards a more restrictive definition of deregulated markets, the coefficient on PE is getting economically stronger. In *IPP ISO Balancing* markets, PE firms are 2.38 percentage points more likely to create a natural gas plant, while in traditional markets the coefficient is 0.03 and statistically insignificant.

Table 5 Column (3) presents the OLS estimates for the *ISO Restructured* deregulation measure. Using this measure, we document that IOUs are 1.50 percentage points less likely to own a greenfield plant in markets with an ISO balancing authority and restructured utilities. *ISO Restructured* is a more restrictive measure of wholesale market deregulation. The ISO restructurings had to be approved by state legislative bodies and were completed at the end of the 1990s, while some ISO balancing markets (but not restructured), such as MISO and SPP, were formed later without state legislative approval.

Even with this timing advantage of the *ISO Restructured* measure, our identification of the effect of deregulation on the creation of new plants and ownership changes relies on the assumption that power plants in deregulated and traditional markets would have followed parallel trends absent the deregulation conditional on observed plant characteristics. However, states and utilities did not randomly choose whether to restructure their electricity markets and we address the possibility of omitted variables bias in several ways.

First, importantly for our interpretation, the deregulated markets were established before our sample period, mostly around 2000, and before wind and solar technologies became competitive, as well as before the shale gas boom (Gilje, Loutskina, and Strahan, 2016). This timeline reduces concerns regarding reverse causality, specifically the alternative hypothesis that electricity markets were deregulated to stimulate the adoption of new technologies.

Second, in Online Appendix Table A.3, we show that state-level natural resources, economic, and political factors do not predict market deregulation. The decision to deregulate markets is not related to variation in state-level solar and wind energy potential, nor is it related to the production of natural gas or coal in a state normalized by the amount of electricity consumption. In line with prior

[31] Our results do not support the Averch and Johnson (1962) argument that regulated utilities engage in more capital investments because they receive an artificially high rate of return on capital. Traditional electricity markets exhibit a lower level of asset creation, potentially because state utility commissions adhere to the "used and useful principle" when permitting new investments. Under this principle, utilities need to show that a power plant will be used and useful to current ratepayers to get the regulator's approval to include a corporate investment in the cost of service.

research, the main factor that predicts wholesale market deregulation is not the average electricity price in a state, but rather the difference between the average electricity price in the residential sector and the average electricity price in the industrial sector (White, 1996; Joskow, 1997).

Third, since the difference between retail and industrial electricity prices on a state level is the main predictor of deregulation, we use it as an instrumental variable for deregulation. The IV is the average residential-industrial price difference *ResidIndPD* on a state level over the 1991–1996 period. We construct the IV over the 1991–1996 period to address the staggered restructuring of electricity markets. The first competitive ISO restructured market, PJM Interconnection, started functioning in 1997, so the IV is measured before any plants operated in a deregulated market. We use the difference between retail and industrial electricity prices to instrument for plants operating in *ISO Restructured* markets. Our analysis examines the baseline effect of *ISO Restructured* and an interaction term of IOUs and *ISO Restructured*, so we estimate two first-stage regressions to instrument for both variables:

$$ISO_{i,t} = \beta_1 ResidIndPD_i + \beta_2 IOU_{i,t} \times ResidIndPD_i + \beta_3 IOU_{i,t} + \gamma' Z_{i,t} + \delta_{ft} + \varepsilon_{i,t}, \qquad (7)$$

$$IOU_{i,t} \times ISO_{i,t} = \beta_1 ResidIndPD_i + \beta_2 IOU_{i,t} \times ResidIndPD_i + \beta_3 IOU_{i,t} + \gamma' Z_{i,t} + \delta_{ft} + \varepsilon_{i,t}. \qquad (8)$$

The control variables $\gamma' Z_{i,t}$ remain the same, but we include only interacted fixed effects on a fuel-time level as the IV does not vary within a state. The second stage uses the predicted values of both variables and examines the effect on ownership of greenfield plants:

$$Greenfield_{i,t} = \beta_1 IOU_{i,t} + \beta_2 \widehat{ISO_{i,t}} + \beta_3 \widehat{IOU_{i,t} \times ISO_{i,t}} + \gamma' Z_{i,t} + \delta_{ft} + \varepsilon_{i,t}. \qquad (9)$$

Online Appendix Table A.4 reports the first stage estimates of both IV regressions. The difference between retail and industrial electricity prices on a state level over the 1991–1996 period strongly predicts whether a power plant i will operate in an ISO-restructured market in period t. In Table 5, the first-stage F-statistic is 94.58, and in most models, we obtain F-statistics well above 100, always passing tests for weak instruments. Column (4) shows that the instrumented coefficient on $IOU_{i,t} \times ISO_{i,t}$ is negative and significant, which implies that IOUs are 1.57 percentage points less likely to own a greenfield plant in deregulated markets, an estimate extremely close to the OLS. The

IV results therefore bolster the causal interpretation that market deregulation is the main economic factor that attracts investments by PE in greenfield power plants.

We can conclude that the shifting ownership due to the creation channel happens only in deregulated markets. New entrants, and especially PE, create more power plants in markets where they have more flexibility to adjust production and pricing and where the wholesale market is not operated by a monopolist utility.

4.2 Selling Power Plants and Market Deregulation

We extend the competing risks models by incorporating controls for market deregulation in the specifications. In Panel A of Table 6, we use the *IPP ISO Balancing* measure, while in Panel B we rely on the instrumented *ISO Restructured* measure. Online Appendix Table A.10 presents the results with the remaining two deregulation measures. In line with the deregulation hypothesis, electricity market regulation influences capital flows from new ownership types, as power plant transactions are more likely to be completed in deregulated markets. Based on Column (1) of Table 6 Panel A, IOUs are three times more likely to sell a plant in an *IPP ISO Balancing* market than in a traditional regulated market, after controlling for fuel type, plant size, and age, and accounting for the competing hazard rate of decommissioning.

The next three columns show that not all new ownership types respond equally to market deregulation. Across the different deregulation measures, PE is consistently more likely to acquire plants in deregulated markets. Based on Column (2) of Panel A, power plants owned by IOUs in an *IPP ISO Balancing* market are 4.64 times more likely to be sold to PE. Acquisitions by institutional investors and foreign corporations are not affected by the market regulation status in a consistent way, but they seem to concentrate more in states with higher climate concerns.

IOUs are also less likely to retire power plants in *ISO Restructured* markets, but the hazard ratios are not significantly different in *IPP ISO Balancing* markets. The potentially reduced decommissioning rates of domestic IOUs in this setting could indicate that some of the sales of IOUs to new owners result in extended operation, the leakage hypothesis.

4.3 Decommissioning Power Plants and Market Deregulation

The decommissioning channel has a more limited role in shifting ownership, but we did observe previously that foreign corporations tend to operate fossil fuel plants for a longer period of time. This leakage could interact with market regulation. Deregulated markets may enable the new ownership types to operate the older fossil fuel plants for a longer period of time.

However, the aggregate decommissioning trends do not support the hypothesis that market deregulation per se enables leakage. Online Appendix Figure A.2 shows that the cumulative decommissioning hazard rate in deregulated markets is 40% higher than in traditional markets: the decommissioning rate is 17.3% in *IPP ISO Balancing* markets versus 12.4% in traditional markets. Differences in fossil fuel plant retirements drive this aggregate effect.

Still, the aggregate trends do not address the hypothesis that the ownership structures display heterogeneity in the decommissioning rates conditional on market regulation. To test this argument, in the hazard models, we include interaction terms between the ownership types and market deregulation indicators (e.g., $IOU_{i,t} \times ISO_{i,t}$):

$$h(t) = h_0(t)exp(\beta_1 IOU_{i,t} + \beta_2 IOU_{i,t} \times ISO_{i,t} + \gamma' Z_{i,t} + \delta_s + \lambda_f). \quad (10)$$

Table 7 shows the decommissioning hazard rate analyses similar to Table 4, but with the inclusion of these new interaction terms. Column (1) shows that the differences in decommissioning hazard ratios seem to be concentrated in deregulated markets, but they are not robust across the different definitions of market regulation and IV estimation.[32] Figure 4 Panel B shows that IOUs and PE have similar decommissioning rates across all definitions of deregulated and traditional markets. For institutional investors, we again confirm that they do not typically hold assets during the decommissioning stage, but they also have very limited exposure to power plants subject to shutdowns as the coefficients cannot even be estimated in some subsamples. The differences in decommissioning rates in *ISO Balancing* markets are primarily between IOUs and foreign corporations. However, this difference is also not consistently observed across all deregulation measures. If we use the *ISO Restructured* definition of deregulated markets, the difference in decommissioning rates between IOUs and foreign corporations is significant in traditional markets.

Overall, the results in Online Appendix Figure A.2 and Table 4 show that there is more decommissioning of plants in deregulated markets, but not necessarily heterogeneity across ownership types. Deregulated markets stimulate all owners jointly to decommission more plants and enable a faster shift from older fossil fuel technologies to newer renewable and fossil fuel technologies. IOUs are retiring more fossil fuel plants in these markets and, critically, new ownership types are not

[32] In the IV specification, we control for time fixed effects in the first stage. The Cox proportional hazard model implicitly accounts for time fixed effects, as it is robust to any baseline hazard function. This feature of Cox proportional hazard models makes it robust to time-specific common factors.

extending the life of these plants on a large scale.[33]

4.4 Implications of Market Deregulation for Power Plant Ownership

We document that the two channels driving the shifting ownership — creating new plants and acquiring existing plants — are stronger in deregulated markets, which attract new entrants such as PE. Especially the creation channel will have a long-lasting impact on the differences between deregulated and traditional markets as the greenfield plants are new and will survive for a long time. The decommissioning channel has a smaller impact on the ownership changes as IOUs and new entrants differ less in the probability of retiring power plants, but deregulated markets induce all owners jointly to decommission more plants.

Figure 5 summarizes the implications of market deregulation on power plant ownership. Panel A shows that new entrants generated 47% of the electricity in 2020 in deregulated markets, and PE alone contributes 31% to the generation in these markets. In traditional markets, the ownership share of new entrants remains almost constant over time and they account for only 9% of the electricity generation in 2020. These trends are substantial and changed the dominant ownership type of power plants across some deregulated states. For example, over the 2005–2020 period, IOUs reduced their ownership share in Pennsylvania (PJM balancing authority) by 62 percentage points, so PE has become the main corporate form of power plant ownership in this state. In 2020, new entrants also accounted for a larger share of the electricity generation than IOUs in Texas (mainly ERCOT balancing authority), New York (NYISO), and Massachusetts (ISO New England).

4.5 Comparing the Role of Market Regulation with Other Economic Factors

Our results highlight the key role of electricity market deregulation in explaining power plant ownership changes. If other economic factors drive these results, they would need to have differential effects on IOUs located in deregulated and traditional markets. In this subsection, we discuss several potential alternative economic factors and show that the effect of market deregulation on ownership changes through the three channels is robust to these factors.

Climate Concerns and Policy Incentives: States where the population displays higher climate concerns may attract more investors through increased demand for new power plants, especially renewables. Higher climate concern among the population could also incentivize more new

[33]This interpretation is in line with the results of Green and Vallee (2022) that banks reduce financing of coal plants, which implies that IOUs cannot sell the power plants to new entrants or use debt to finance these assets.

investors to commit capital to greenfield projects as they could expect these states to adopt stricter regulations against old power plants. In addition, states implement various tax and production-based incentives to stimulate the adoption of renewable energy, and ownership types may respond differently to these incentives.

In the greenfield specifications (Table 5), we find that the interaction term of IOUs and the climate concern percentile ranking is mostly insignificant suggesting that the differences in the probability of financing new power plants across regulatory regimes are not driven by differences in the sensitivity of PE and foreign corporations to climate concerns among the population. The differences in ownership of greenfield plants are also not captured by differences in the sensitivity of IOUs, PE, and foreign corporations to renewable energy policy incentives. For the sales channel (Table 6), states with higher climate concerns experience more sales of plants from IOUs to the new ownership types, but this relation does not affect the role of market deregulation. We also do not find robust evidence of climate concerns and policy incentives' effects on decommissioning rates (Table 7). The differences in ownership of decommissioned plants do not merely reflect differences in the sensitivity of IOUs, PE, and foreign corporations to climate concerns or renewable energy policy incentives.

In the main greenfield and decommissioning analyses, we include an interaction term of IOUs with the *Renewable Incentives* index. In Online Appendix Figure A.3, we estimate specifications that include separate interaction terms of IOUs with each of the components of this index: with the three indicators if a state has corporate tax, property tax, and sales tax incentives for renewable energy, as well as with the two indicators if a state has production incentives or feed-in tariffs for renewable energy. The specifications in Panel A confirm that IOUs are less likely to own greenfield plants in deregulated markets and these results are robust to controlling separately for the five renewable policy incentives. Panel B presents a similar robustness test for decommissioning of power plants. Our baseline specifications do not find significant and consistent heterogeneity across ownership types in their sensitivity of decommissioning decisions to market regulation. The robustness test with five separate indicators for renewable policy measures documents similar results.

Credit Ratings and ESG Ratings: An alternative hypothesis is that electricity market regulation correlates with IOU characteristics, such as corporate credit ratings or ESG ratings. These corporate characteristics, rather than market competitiveness, might then explain the ownership changes. Under this hypothesis, firms with weaker credit ratings are more likely to be financially constrained and might engage in less plant creation or more plant destruction. Firms with higher

ESG ratings may favor the creation of solar and wind farms and decommissioning of fossil fuel plants. This hypothesis predicts that only low ESG or low credit rating IOUs would be less likely to create greenfield power plants and the differences should be insignificant for high-ranked IOUs regardless of market regulation.

Figure 6 shows that across all ESG and credit rating categories, IOUs are less likely to own greenfield plants. Importantly, the interaction effects with market deregulation remain robust and significant in almost all ESG rating and credit rating categories. In Online Appendix Figure A.4, we also find that IOUs of all ESG and credit rating categories are less likely to create new solar and wind plants. Moreover, the lower creation of new natural gas plants by IOUs is concentrated in firms with lower ESG ratings (counterintuitively) and lower credit ratings. Online Appendix Figure A.5 finds no variation of interest in the decommissioning rates across the ESG or credit rating categories. To the extent that IOUs are more likely to decommission, there is no specific ESG or credit rating category that is more likely to do it in a robust fashion. Online Appendix Table A.11 also shows that the role of market deregulation and plant characteristics in explaining domestic IOUs' selling and decommissioning decisions is robust to ESG and credit rating controls.

Legacy Assets: A final alternative hypothesis we consider is that IOUs might be subject to institutional inertia around legacy assets. Under this hypothesis, IOUs with a greater foothold in legacy assets, such as coal power plants, would face greater internal agency frictions that limit the firm's investments in newer, competing technologies (e.g. Stein, 1997; Scharfstein and Stein, 2000). We test this explanation using IOU splits in quartiles based on the percentage of coal capacity as a share of the firm's total capacity, as shown in Panel C of Figure 6. Under the alternative legacy hypothesis, IOUs with greater exposure to coal assets should exhibit a lower probability of financing the adoption of new technologies. We do not find supporting evidence for the legacy hypothesis, as IOUs across all quartiles are equally less likely to create new power plants. Importantly, the negative effect of market deregulation on the creation of power plants by IOUs is economically robust and similar across all quartiles.

Moreover it is not that surprising to see that IOUs do not seem responsive to legacy asset shares in their investment decisions, as there are several mechanisms to avoid legal exposure. First, shareholders could establish new listed firms devoted to the creation of new assets. Second, IOUs can spin off income-generating assets (whether legacy or new) into separate YieldCo companies, as IOUs NRG and NextEra have done with NRG Yield Inc and NextEra Energy Partners respectively. Our definition of IOUs picks up such newly listed firms and YieldCos, but these represent a very small share of installed capacity.

5 Power Plant Operating Performance

The previous analysis examines only ownership of power plants. In this section, we use the capacity factor and heat rate to study the intensity and efficiency of power plant operation. The homogeneity of the output product makes the electricity generation sector a particularly appropriate setting for studying operating performance.

The capacity factor, which equals the ratio of electricity generation to capacity, reflects the *intensity* with which assets are operated. Examining it extends the previous analysis in two ways. First, if we observe a higher operating intensity by the new entrants, it could be an additional explanatory factor for the rise of new entrants as a share of total generation that would not require changes in ownership. Second, if the new entrants operate legacy power plants with a higher intensity, it could represent an alternative form of leakage.

The heat rate, which equals the ratio of fuel consumption to electricity generation, reflects the *efficiency* with which assets are operated. If the shift in ownership truly reflects new entrants' better positioning to implement new technologies, consistent with the Arrow hypothesis, we would hypothesize that the new entrants are operating both acquired and newly created power plants more efficiently.

We use the operating performance measures as dependent variables in the following model:

$$Y_{i,t} = \beta_1 IOU_{i,t} + \beta_2 ISO_{i,t} + \beta_3 IOU_{i,t} \times ISO_{i,t} + \gamma' Z_{i,t} + \delta_{fst} + \varepsilon_{i,t}. \tag{11}$$

Columns (1) to (4) of Table 8 show the results where $Y_{i,t}$ is the power plant's capacity factor, while in Columns (5) to (8), $Y_{i,t}$ is the heat rate. The specifications include δ_{fst}, which are interacted fuel-state-time fixed effects and effectively limit the analysis to comparing the operating performance of plants using the same fuel type, located in the same state, and in the same moment of time. This saturated set of fixed effects addresses to a large extent differences in the prices of resources (e.g., coal and natural gas prices) as well as weather conditions (e.g., sunshine hours in different months). In the models, we control for whether a plant is in a greenfield or decommissioning stage, as power plants in these periods operate under significantly lower capacity factors as well as higher heat rates.[34]

[34] Operating performance is in fact even lower in the first and last month as the coefficients on *Greenfield 1m* and

Column (1) of Table 8 shows that IOU plants have a 0.02 higher capacity factor. This result goes against the hypotheses that changes in operating intensity could be an additional channel driving the ownership shift, or that leakage is occurring through higher operating intensity of the new ownership types. As shown in Column (2), the difference is particularly pronounced relative to PE-owned plants, which operate at a capacity factor that is 0.03 *lower* than IOUs. Columns (3) and (4) show that the difference in operating intensity between IOUs and new ownership types is concentrated in traditional markets, where the production allocation is controlled by a monopolist utility.[35] We emphasize that operating a power plant less intensively is not necessarily a sign of weaker operating performance; it can be even profit-enhancing if the owner exercises market power or if it is unprofitable to produce in some hours or at higher capacity utilization for any reason (Jha and Leslie, 2023).

The results in columns (5)–(8) show that there are also differences across ownership types in power plant operating efficiency, as measured by heat rates. Based on Column (5), IOU plants have a 0.62 higher heat rate than plants owned by the new entrants. This coefficient implies that power plants owned by IOUs operate less efficiently and use around 5% (= 0.616 / 11.324) more fuel to produce one unit of electricity when we compare plants using the same fuel, located in the same state, and at the same moment of time. Power plants owned by PE, institutional investors, and foreign corporations all consume less fuel and operate more efficiently. The differences in operating efficiency between IOUs and new entrants seem to be relatively larger in deregulated markets but the interactions are only statistically significant under the *IPP ISO Balancing* measure of deregulation and not under the instrumented *ISO Restructured* measure.

The lower heat rate of new entrants is consistent with the hypothesis that they are implementing new technologies and have an operational advantage relative to the incumbent IOUs. This operational advantage can come from several possible sources, including the protection of IOUs from market mechanisms, less productive management cultures, and reduced incentives due to rate-of-return regulation. However, we note that the lower heat rates are seen not only in PE, but also in the other new ownership types, foreign corporations and institutional investors. For institutional investors, much of the entry is very likely in the form of co-investments, so that institutional investors are

Decommissioned 1m indicator variables are negative and significant. A large part of the negative coefficient for the first and last months is likely mechanical, as power plants do not always operate for the entire month and could be started or decommissioned in the middle of the month. We include separate indicators for the first and last months to isolate this mechanical effect.

[35] IOUs may in these circumstances of traditional markets have the incentive to utilize power plants at higher capacity in these markets, as they are subject to used-and-useful regulation and to maintain their rate base.

also benefiting from PE restructuring activities.[36] The fact that foreign corporations operate at lower heat rates under comparable conditions suggests that at least some of the reduced incentives of IOUs are specific to U.S. publicly listed corporations and utilities.

Online Appendix Table A.12 examines separately the operating performance of different fuel types. We see that the difference in operating performance between IOUs and new ownership structures is driven primarily by natural gas power plants, consistent with the interpretation that, in this fuel type, the owners have flexibility as to when to operate a plant, and may face regulatory incentives to increase operating intensity in traditional markets.

The previous analysis studied all power plants, not only those that experienced changes in ownership. However, such an analysis may not be sufficient to disentangle whether the new entrants select more efficient plants (within the same state, fuel type, and time period), or whether their ownership leads to operational improvements. In Table 9 Panel A, we focus only on plants that were sold by IOUs and estimate stacked difference-in-difference specifications:

$$Y_{i,t} = \beta Post \times Treated + \gamma' Z_{i,t} + \delta_{ic} + \mu_{st} + \nu_{ct} + \varepsilon_{i,t}. \tag{12}$$

The treatment event is a power plant sale from IOUs to the new ownership types. The analysis focuses on an event window of 48 months, covering two years pre- and post-sale. In the subsample of only treated power plants in Column (1), we observe that the operating intensity does not change after the ownership change, whereas in Column (3), we see that the new owners operate these power plants more efficiently than the previous IOU owners with a 0.31 lower heat rate.

In Columns (2) and (4), we stack each treated power plant with a matched never-treated power plant that has been always owned by IOUs during our sample period. We match power plants exactly based on fuel type and prime mover, and nearest-neighbor based on plant capacity and age using the Mahalanobis distance measure. In line with Cengiz, Dube, Lindner, and Zipperer (2019) and Baker, Larcker, and Wang (2022), we include the following set of fixed effects: δ_{ic} are interacted plant-prime-mover and stacked cohort fixed effects, μ_{st} are interacted state and time year-month fixed effects, and ν_{ct} are interacted cohort and time fixed effects. The stacked difference-in-difference results in Column (4) show that the new owners improve the plant's operating efficiency. The heat rate of the acquired plants declines by 0.44 in the 24 months after the IOUs sell these plants.

[36] For example, Canada Pension Plan Investment Board co-invested with Energy Capital Partners in the buyout of Calpine Corporation; British Columbia Investment Management Corporation co-invested with Macquarie Infrastructure and Real Assets in the buyout of Cleco Corporation; and Alberta Investment Management Corporation co-invested with Macquarie Infrastructure Partners in the buyout of Puget Sound Energy.

The above results on ownership changes suggest that new owners operate power plants more efficiently when ownership is transferred. They do not show whether new ownership types also create more efficient power plants, which is important given our findings that creation drives a large part of the ownership changes. In Table 9 Panel B, we compare the operating performance of newly created power plants by IOUs with plants created by the new ownership types during our sample period. The greenfield power plants do not differ in terms of operating intensity across the ownership types, but new entrants create more efficient power plants. Based on Column (4), which studies a matched subsample of new plants, power plants created by IOUs have a 0.67 higher heat rate than power plants created by new entrants.

Similar to our findings that new owners operate power plants more efficiently, Demirer and Karaduman (2023) find that high-productivity firms acquire plants and increase their efficiency by 4%. Bai and Wu (2023) focus on a smaller sample of PE acquirers and also document that acquired plants operate with a lower heat rate, which translates into reduced fuel consumption and emissions. We confirm the finding that PE acquisition improves operating efficiency, while at the same time we show that the other new ownership types exhibit similar effects. We also show that the new ownership types create more efficient plants, which is important given that the ownership changes are so heavily driven by creation and decommissioning. These two channels cannot be picked up in a standard difference-in-difference model exploiting ownership changes through acquisitions.

Overall, we find evidence consistent with the hypothesis that the new owners enter electricity markets through creation and acquisition because they are better positioned to implement new technologies. Our evidence does not suggest that the new owners are contributing to leakage via increased operating intensity or lower operating efficiency. The new entrants do not appear to be exploiting some type of arbitrage to avoid the scrutiny of regulators or the public, as their operating efficiency is higher and operating intensity is similar to or lower than the domestic IOU incumbents.

6 Conclusion

Regardless of the exact policy direction, stated commitments to achieve greater energy independence and reduce greenhouse gas emissions will require substantial capital investments to change the composition of assets that produce electricity. Using data on U.S. power plants accounting for 99% of the electricity generation over 2005–2020 period, we find that incumbent domestic IOUs have reduced their ownership from 70% to 54%, while new entrants, such as private equity, institutional investors, and foreign corporations, have increased their ownership stakes from 7% to 24%. The financing mode matters beyond the regulatory structure of local electricity markets, and it drives the ability of new entrants to finance the adoption of new technologies and restructure existing assets.

PE and foreign corporations have increased their ownership share substantially through the creation of new solar, wind, and natural gas power plants in deregulated wholesale electricity markets. This result highlights a new role for non-venture PE, namely in large-scale asset creation, that prior research on PE has not explored. We find limited support for the leakage hypothesis that incumbent domestic IOUs, which are subject to higher disclosure requirements and public scrutiny, are more likely to sell older fossil fuel power plants to the new ownership types. Conditional on fuel type and age, foreign corporations operate power plants for longer than IOUs, while PE has similar decommissioning rates. Institutional investors increase their ownership of power plants, but focus on operational assets and are not involved in asset creation or destruction.

In terms of operating performance, IOUs operate electricity generating assets with higher intensity in traditional markets with limited competition, but they are less efficient. The new ownership types create more efficient power plants with a lower heat rate and improve the efficiency of acquired plants. Power plants owned by the new entrants consume around 5% less fuel per unit of produced electricity.

Recent federal legislation, including the Infrastructure Investment and Jobs Act and the Inflation Reduction Act, has provided incentives for power plant investment, and different owners may respond differently to such incentives. Our results highlight that new entrants, such as PE and foreign corporations, have played an important role in creating new and more efficient power plants, but the impacts that these changes in ownership structure will have on businesses and consumers are yet to be determined.

These results point to two key additional questions about the potential tradeoffs in bringing new sources of financing to the electricity sector. First, what will be the implications of the shift in ownership types for grid stability, particularly in emergencies when electricity grids cannot handle demand, such as in the Texas winter storm incident of February 2021? Second, what will the financial effects be on business and consumers, as new owners may offer different pricing terms and deliver wholesale electricity under a different mix of contract duration and full period versus peak period sales? We leave these questions open for further research.

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Figure 1: Ownership and Electricity Generation

This figure presents the aggregate ownership by the eight categories of owners as a percentage of monthly electricity generation over the 2005–2020 period. Electricity generation is measured as the total electrical output net of the power plant service. If multiple ownership types own a power plant, we divide the ownership and generation equally across the ownership types (i.e., if PE and IOUs jointly own a power plant, we assume that each ownership type owns 50% of the power plant and accounts for 50% of the electricity output).

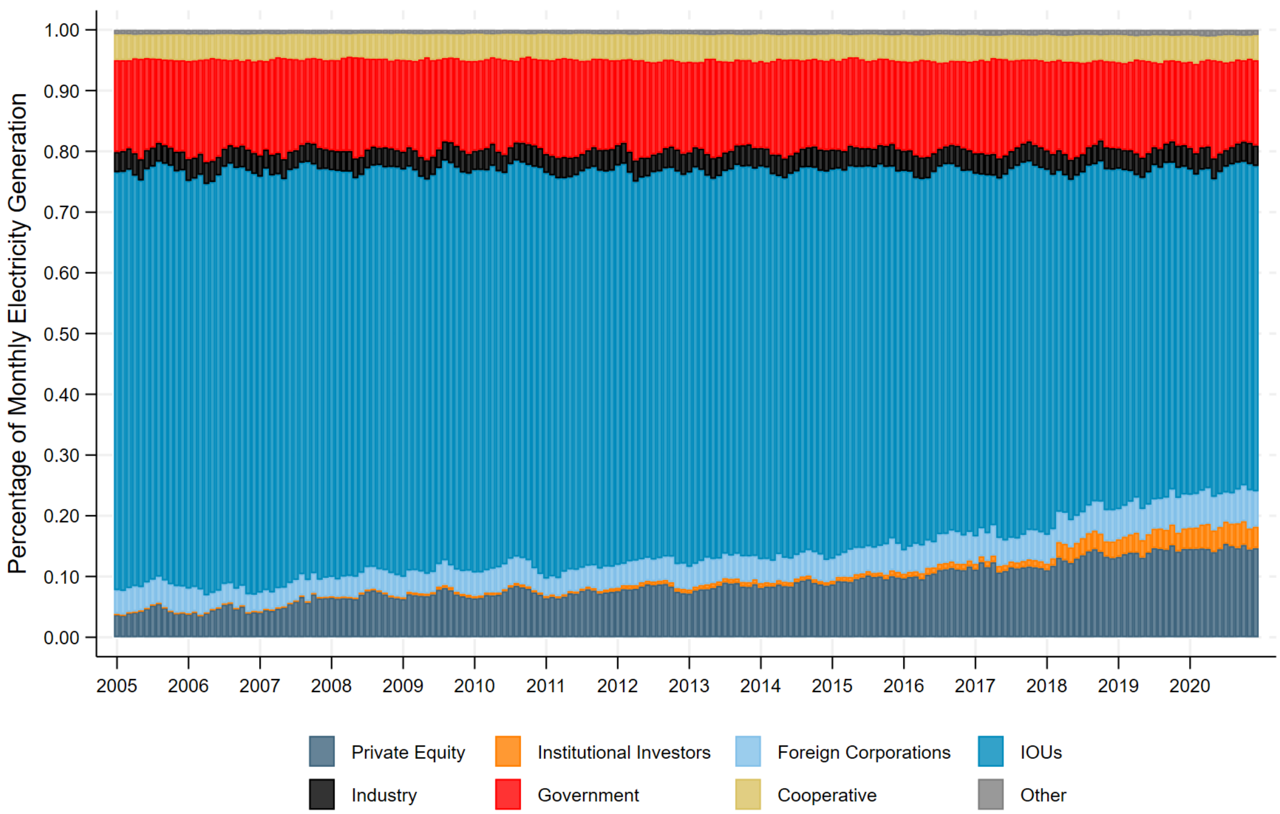


Figure 2: Ownership and Electricity Generation by Fuel Type

This figure presents the ownership by the eight owner types for the 6 main fuel types (out of 19 fuel types in the EIA classification) based on the monthly electricity generation. For natural gas, coal, and nuclear, the y-axis is scaled to 200 TWh, while for hydro, wind, and solar the y-axis is scaled to 35 TWh.

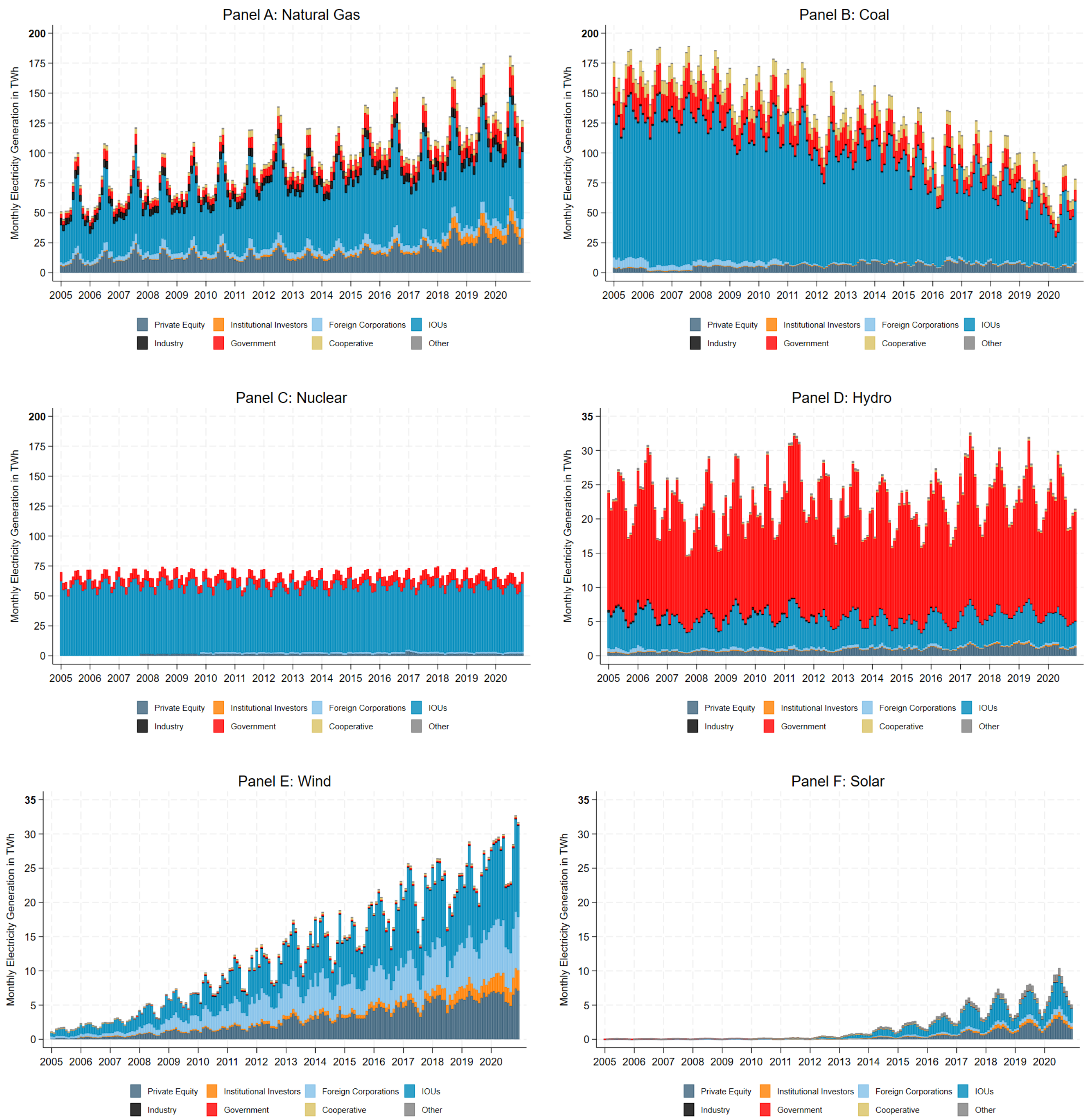


Figure 3: Ownership of Greenfield Power Plants

This figure presents coefficients for PE, institutional investors, and foreign corporations from an analysis that uses the same specifications as in Table 2. Observations are at the plant-prime-mover-month level and weighted by capacity. In Panel A, the dependent variable captures all greenfield power plants. In Panels B and C, we decompose it to capture solar & wind and natural gas greenfield plants. The omitted category in all specifications is IOUs, and we control for the remaining ownership categories. The specifications include interacted fuel-type, state, and year-month fixed effects, and plant-prime-mover fixed effects. We double-cluster the standard errors by plant-prime-mover and year-month.

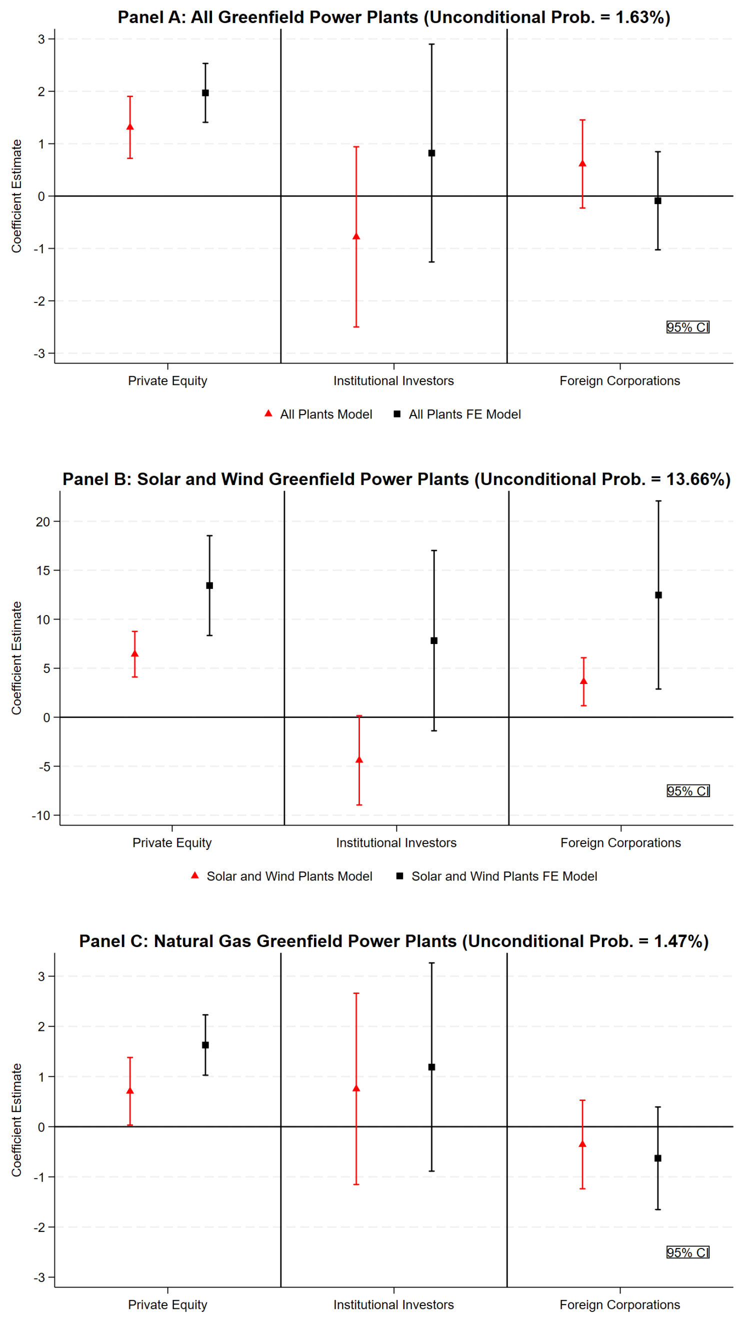
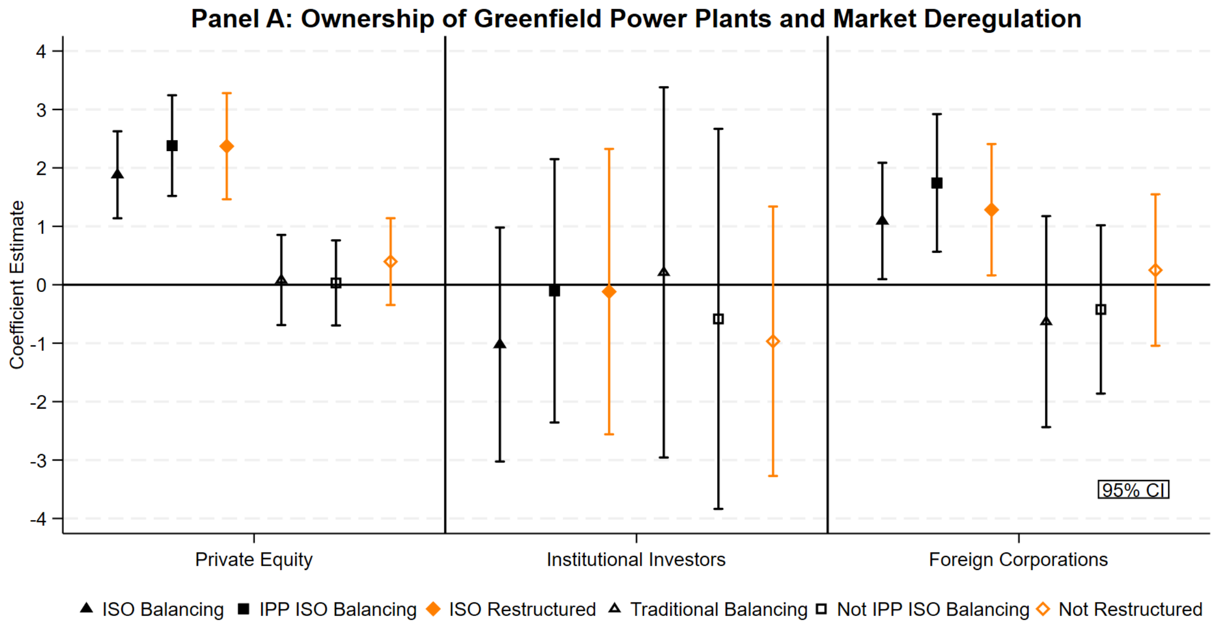


Figure 4: Shifting Ownership Channels and Market Deregulation

The figures present coefficients for PE, institutional investors, and foreign corporations. The omitted category in all specifications is *IOUs*, and we control for the remaining ownership categories. Using sample splits, we estimate the role of ownership separately for power plants located in deregulated markets (ISO Balancing, IPP ISO Balancing, or ISO Restructured markets) and traditional markets. Panel A analyzes the creation channel using OLS models and observations weighted by capacity. These specifications include interacted fuel-type, state, and year-month fixed effects. Panel B examines the decommissioning channel using Cox hazard specifications and the sample includes plants with a capacity of at least 20MW. These specifications include fuel-type and state fixed effects.



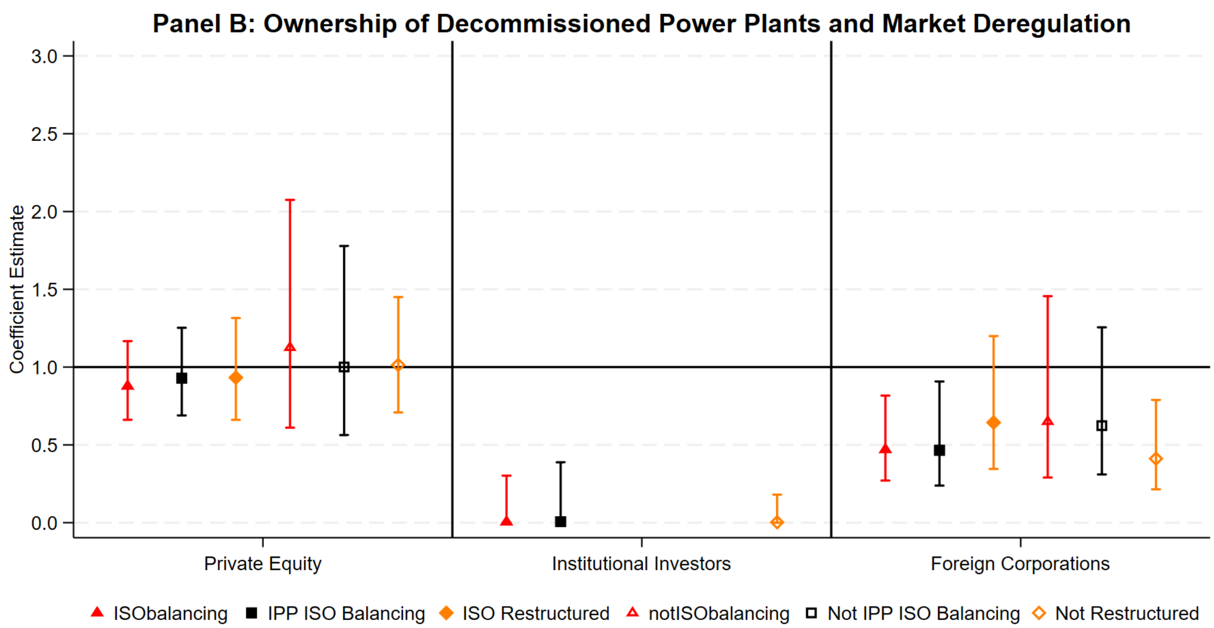


Figure 5: Ownership and Electricity Generation by Market Regulation and State

Panels A and B present the aggregate ownership by private equity, institutional investors, and foreign corporations as a percentage of monthly electricity generation over the 2005–2020 period. Panel A shows the ownership stakes of power plants that operate in an *IPP ISO Balancing* market. Panel B shows the ownership stakes in traditional balancing markets. Panels C to F display the changes in the ownership stakes of IOUs, private equity, institutional investors, and foreign corporations by state between 2005 and 2020. The changes are measured in percentage points of the state's electricity generation.

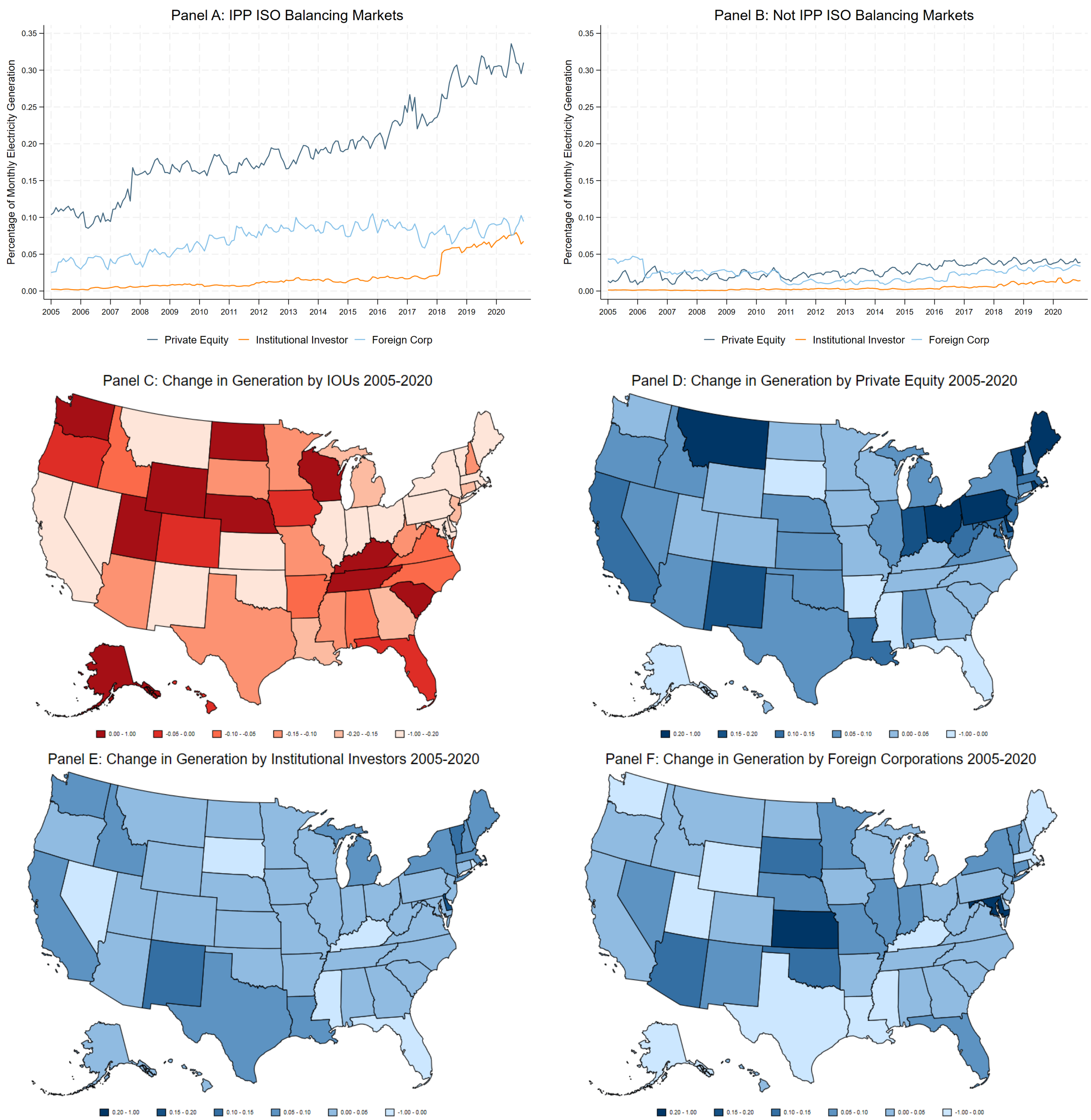


Figure 6: IOUs Split by Characteristics and Greenfield Plants

This figure extends the analysis from Table 5. We split the IOUs into quartiles based on three potential constraints: ESG ratings, credit ratings, and the percentage of coal assets from total capacity.

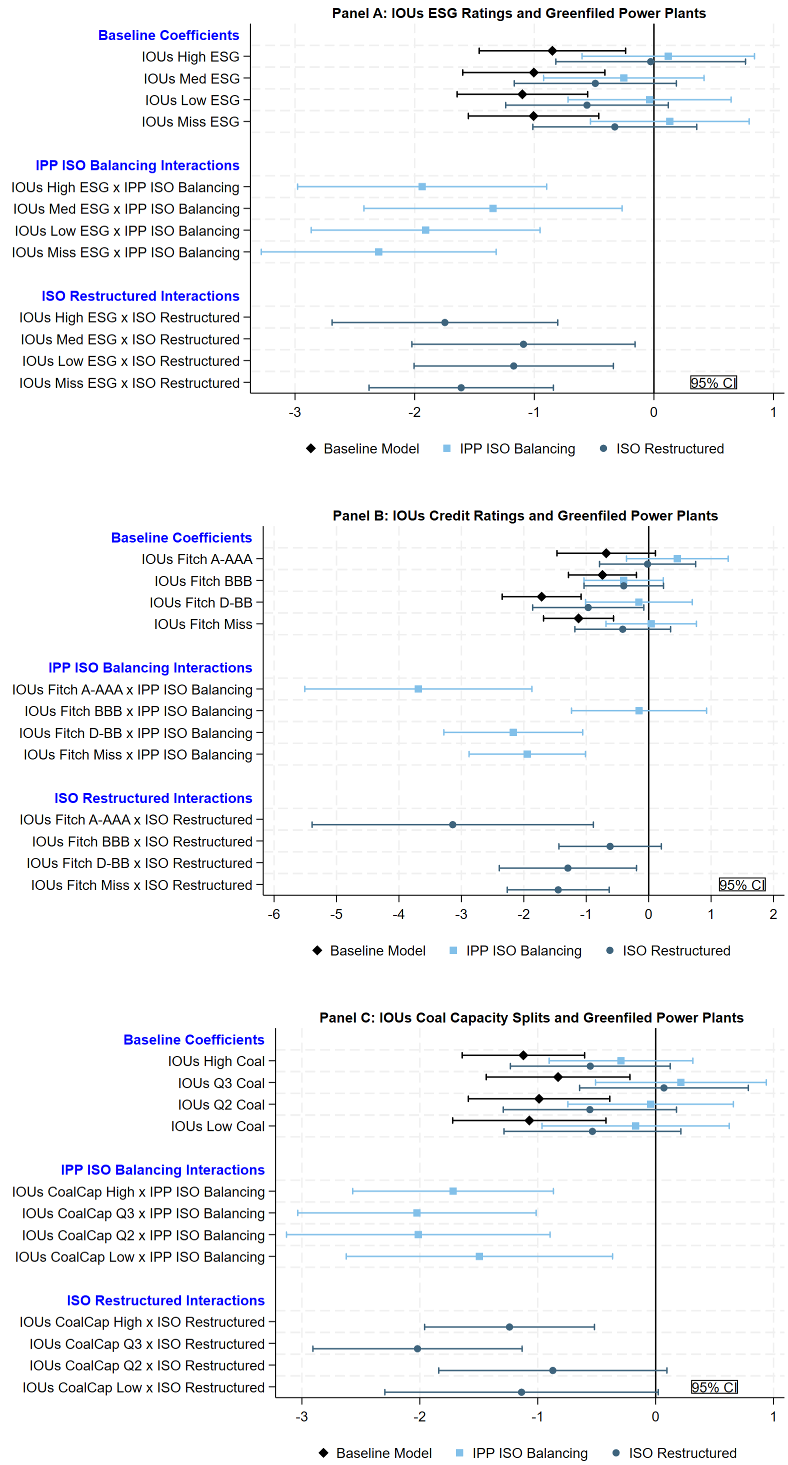


Table 1: EIA Power Plants

The table presents summary statistics on a plant-prime-mover-month level for all power plants and separately for the main fuel types: natural gas, coal, nuclear, hydro, wind, and solar. All statistics are the weighted means by capacity. Panel B reports statistics for the power plant characteristics. *Capacity* is the nameplate capacity in GWh. *Capacity Factor* is the ratio of monthly generation to capacity. *Heat Rate* is the ratio of fuel consumption in millions of Btu to electricity generation in MWh. *Age* presents the plant age in years. *Greenfield* is an indicator for the first 12 months when a plant starts operating. *Decommissioned* is an indicator for the last 12 months when a plant is still operating. Panel C reports the average ownership by the eight categories in percent. If multiple ownership types own a power plant, we divide the ownership equally across the ownership types. Panel D presents statistics on electricity markets. *ISO Balancing* is an indicator for power plants that participate in a wholesale market administered by an Independent System Operator. *IPP ISO Balancing* is an indicator for power plants that participate in an ISO Balancing market and are owned by an independent power producer rather than a regulated electric utility. *ISO Restructured* is an indicator for power plants that participate in a wholesale market administered by an ISO balancing authority and are located in areas with restructured utilities. *ResidIndPD* is the difference between the average residential and industrial electricity prices in a state over the 1991–1996 period. *Climate Concern* is the percentile ranking of the state where the plant is located based on the percentage of the state population who think that global warming is happening. *Renewables Incentives* is an aggregate index of three indicators if a state has corporate tax, property tax, and sales tax incentives for renewable energy as well as two indicators if a state has production or feed-in tariffs incentives for renewable energy.

	All	**NatGas**	**Coal**	**Nuclear**	**Hydro**	**Wind**	**Solar**
Panel A: Power Plants Sample							
# Unique Plants	11,593	3,024	751	66	1,500	1,294	3,941
# Unique Plants-Prime-Mover	13,261	4,142	867	66	1,500	1,294	3,941
# Unique Greenfield	6,082	752	36	0	53	1,031	3,630
# Unique Decommissioned	1,949	950	311	10	94	94	42
Observations	1,509,346	572,867	115,426	12,215	270,290	135,683	188,066
Panel B: Power Plant Characteristics							
Capacity (GWh)	0.980	0.584	1.426	2.037	1.090	0.176	0.100
Capacity Factor	0.403	0.264	0.533	0.855	0.399	0.328	0.241
Heat Rate		11.891	10.686	10.457			
Age (Years)	30.905	21.647	41.945	33.091	58.883	6.155	2.912
Greenfield	0.016	0.017	0.003	0.000	0.000	0.116	0.244
Decommissioned	0.010	0.010	0.017	0.005	0.000	0.002	0.001
Panel C: Power Plant Ownership							
IOUs	0.591	0.547	0.706	0.843	0.209	0.421	0.472
Private Equity (PE)	0.109	0.167	0.053	0.019	0.034	0.223	0.250
Institutional Investors	0.011	0.017	0.002	0.000	0.003	0.049	0.046
Foreign Corporations	0.048	0.054	0.021	0.014	0.014	0.271	0.066
Industry	0.026	0.041	0.021	0.000	0.006	0.001	0.006
Government	0.159	0.112	0.132	0.124	0.716	0.014	0.007
Cooperative	0.047	0.057	0.064	0.000	0.007	0.010	0.006
Other	0.008	0.007	0.001	0.000	0.009	0.012	0.147
Panel D: Wholesale Electricity Markets							
ISO Balancing	0.608	0.635	0.607	0.631	0.267	0.788	0.611
IPP ISO Balancing	0.356	0.423	0.241	0.444	0.064	0.686	0.583
ISO Restructured	0.350	0.375	0.319	0.482	0.119	0.350	0.158
ResidIndPD	9.778	10.106	9.305	10.326	8.567	9.923	10.050
Climate Concern	0.529	0.568	0.410	0.558	0.650	0.529	0.737
Renewables Incentives	2.179	2.228	2.066	2.065	2.198	2.705	2.598

Table 2: Ownership of New Greenfield Power Plants

In this table, observations are at the plant-prime-mover-month level and weighted by nameplate capacity. The dependent variable is greenfield power plants and equals one for the first 12 months of plant operation. We measure the ownership by domestic publicly listed investor-owned utilities (*IOUs*), and the omitted categories are PE, institutional investors, and foreign corporations. We also control for the ownership by industry firms, government, cooperatives, and others. *ln Plant Capacity* is the natural logarithm of a plant's monthly capacity. The specifications include interacted fuel-type, state, and year-month fixed effects. In Columns (2), (4), and (6), the specifications also include plant-prime-mover fixed effects. We double cluster standard errors by plant-prime-mover and time, and report standard errors in brackets. *$p < .10$; **$p < .05$; ***$p < .01$.

	All Plants		**Solar & Wind**		**Natural Gas**	
	(1)	(2)	(3)	(4)	(5)	(6)
Unconditional Prob.	1.63%	1.63%	13.66%	13.66%	1.47%	1.47%
IOUs	-0.990***	-1.491***	-4.209***	-12.722***	-0.478*	-1.215***
	[0.249]	[0.252]	[0.993]	[2.575]	[0.282]	[0.275]
ln Plant Capacity	0.153**		2.784***		0.025	
	[0.062]		[0.632]		[0.095]	
Other Owners	Yes	Yes	Yes	Yes	Yes	Yes
Fuel-State-Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Plant FE		Yes		Yes		Yes
Observations	1,410,850	1,410,618	322,113	321,905	519,011	519,005
Adjusted R-squared	0.200	0.403	0.167	0.409	0.153	0.339

Table 3: Competing Risks Model: Sales and Decommissioning of Power Plants

Observations are at the plant-prime-mover-month level and the sample includes only power plants with a capacity of at least 20MW. We present the hazard ratios of a survival analysis using a competing risks model. The sample includes all power plants that have been owned by *IOUs* at any moment during our sample period. The analysis compares two competing outcomes: a complete sale of a power plant to any new ownership type (not a partial sale or reduced ownership stake) and a decommissioning of a plant. In Columns (3) to (5), the analysis decomposes the sales outcome into four competing sub-outcomes: sell to PE, sell to institutional investors (II), sell to foreign corporations (Fgn), sell to any other new ownership type, such as government or cooperative (not reported but it is a competing outcome). *ln Plant Capacity* is the natural logarithm of a plant's monthly capacity. *ln Plant Age* is the natural logarithm of plant age in years. The specifications include 19 fuel-type fixed effects and we present the coefficients for coal, nuclear, hydro, wind, and solar power plants (the omitted category is natural gas plants). Columns (2) and (7) also include state fixed effects. We cluster standard errors by plant-prime-mover and report standard errors in brackets. *$p < .10$; **$p < .05$; ***$p < .01$.

Event of Interest:	Sell All (1)	Sell All (2)	Sell to PE (3)	Sell to II (4)	Sell to Fgn (5)	Dec. (6)	Dec. (7)
#Events of Interest:	656	656	544	178	67	377	377
#Competing Events:	377	377	489	855	966	656	656
#Total Power Plants:	2,767	2,767	2,767	2,767	2,767	2,767	2,767
ln Plant Capacity	0.883***	0.884***	0.926*	1.001	0.692***	0.686***	0.615***
	[0.036]	[0.039]	[0.041]	[0.075]	[0.084]	[0.031]	[0.030]
ln Plant Age	1.204***	1.166***	1.214***	1.199***	1.037	5.332***	5.443***
	[0.045]	[0.049]	[0.049]	[0.075]	[0.118]	[0.835]	[0.921]
Coal	0.315***	0.438***	0.298***	0.124***	0.659	1.794***	1.994***
	[0.059]	[0.088]	[0.060]	[0.059]	[0.306]	[0.256]	[0.292]
Hydro	0.203***	0.248***	0.193***	0.157***	0.096**	0.010***	0.010***
	[0.048]	[0.064]	[0.052]	[0.081]	[0.098]	[0.006]	[0.006]
Nuclear	0.043***	0.033***	0.050***	0.000***	0.000***	0.936	1.188
	[0.043]	[0.034]	[0.050]	[0.000]	[0.000]	[0.339]	[0.457]
Solar	0.180***	0.166***	0.253**	0.136***	0.061**	0.000***	0.000***
	[0.049]	[0.047]	[0.071]	[0.086]	[0.068]	[0.000]	[0.000]
Wind	0.654***	0.874	0.705**	1.118	0.192***	0.565	0.523
	[0.087]	[0.119]	[0.104]	[0.245]	[0.115]	[0.233]	[0.215]
Fuel-Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Plant State FE		Yes					Yes
Observations	326,312	326,312	326,312	326,312	326,312	326,312	326,312

Table 4: Ownership of Decommissioned Power Plants

In this table, observations are at the plant-prime-mover-month level and the sample includes only power plants with a capacity of at least 20MW. We present the hazard ratios of a survival analysis using the Cox proportional hazard model. The event of interest is a complete decommissioning of a power plant (not partial retirement of one generator). *#Power Plants* reports the number of unique plant-prime-mover units included in the survival analysis, while *#Decommissioned* reports the number of unique plant-prime-mover units that are retired by the end of the survival analysis. We measure the ownership by IOUs, private equity, institutional investors, and foreign corporations. We also control for the ownership by industry firms, government, cooperatives, and others. *ln Plant Capacity* is the natural logarithm of a plant's monthly capacity. *ln Plant Age* is the natural logarithm of plant age in years. The specifications include fuel-type and state fixed effects. We cluster standard errors by plant-prime-mover and report standard errors in brackets. $^{*}p < .10$; $^{**}p < .05$; $^{***}p < .01$.

	All Plants		**Coal**		**Natural Gas**	
	(1)	(2)	(3)	(4)	(5)	(6)
#Power Plants:	5,392	5,392	988	988	2,315	2,315
#Decommissioned:	758	758	311	311	335	335
IOUs	1.316**		1.502*		1.035	
	[0.156]		[0.317]		[0.182]	
Private Equity		1.007		0.712		1.351
		[0.128]		[0.161]		[0.256]
Institutional Investors		0.002***				0.004***
		[0.004]				[0.008]
Foreign Corporations		0.508***		0.568		0.676
		[0.117]		[0.229]		[0.231]
ln Plant Capacity	0.606***	0.610***	0.523***	0.524***	0.649***	0.657***
	[0.023]	[0.023]	[0.029]	[0.029]	[0.043]	[0.043]
ln Plant Age	3.230***	3.221***	3.941***	3.920***	3.243***	3.246***
	[0.281]	[0.275]	[0.810]	[0.805]	[0.371]	[0.369]
Other Owners	Yes	Yes	Yes	Yes	Yes	Yes
Fuel-Type FE	Yes	Yes	Yes	Yes	Yes	Yes
Plant State FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	753,396	753,396	132,948	132,948	344,290	344,290

Table 5: Creation Channel and Market Deregulation

In this table, observations are at the plant-prime-mover-month level and weighted by capacity. The dependent variable is greenfield power plants and equals one for the first 12 months of plant operation. We measure the ownership by IOUs, PE, institutional investors, and foreign corporations. We also control for the ownership by industry firms, government, cooperatives, and others. *ISO Balancing*, *IPP ISO Balancing*, and *ISO Restructured* are indicators for power plants operating in a deregulated electricity market. Column (4) presents the second stage results of an IV model where we instrument the *ISO Restructured* and *IOUs* $\times$ *ISO Restructured* variables with the difference between the average residential and industrial electricity prices in a state over the 1991–1996 period. Online Appendix Table A.4 reports the first stage estimates of both IV regressions. We also control for the interactions of IOU ownership with *Climate Concern* percentile ranking and *Renewables Incentives* aggregate index. *ln Plant Capacity* is the natural logarithm of a plant's monthly capacity. The specifications include interacted fuel-type, state, and year-month fixed effects. We double cluster standard errors by plant-prime-mover and time, and report standard errors in brackets. For the IV model, we present the Kleibergen-Paap rk Wald F statistic of the first-stage regressions. *$p < .10$; **$p < .05$; ***$p < .01$.

Greenfield Power Plants (Unconditional Prob. = 1.63%)	(1)	(2)	(3)	(4)
IOUs	-0.101	-0.376	-0.632	-0.711**
	[0.437]	[0.434]	[0.437]	[0.335]
ISO Balancing	0.086			
	[0.325]			
IOUs × ISO Balancing	-1.159***			
	[0.332]			
IPP ISO Balancing		0.457		
		[0.351]		
IOUs × IPP ISO Balancing		-1.914***		
		[0.419]		
ISO Restructured			0.678	0.276
			[0.463]	[0.375]
IOUs × ISO Restructured			-1.501***	-1.571***
			[0.385]	[0.543]
IOUs × Climate Concern	0.059	0.650	0.230	0.737*
	[0.635]	[0.642]	[0.657]	[0.428]
IOUs × Renewables Incentives	-0.044	0.005	0.067	0.065
	[0.158]	[0.156]	[0.157]	[0.087]
ln Plant Capacity	0.171***	0.174***	0.151**	0.053
	[0.063]	[0.062]	[0.062]	[0.052]
Other Owners	Yes	Yes	Yes	Yes
Fuel-State-Year-Month FE	Yes	Yes	Yes	
Fuel-Year-Month FE				Yes
Observations	1,410,850	1,410,850	1,410,850	1,492,665
Adjusted R-squared	0.200	0.201	0.200	
K-P rk F-Stat				94.584
Model	OLS	OLS	OLS	IV

Table 6: Sales Channel and Market Deregulation

Observations are at the plant-prime-mover-month level and the sample includes only power plants with a capacity of at least 20MW. We present the hazard ratios of a survival analysis using a competing risks model. The sample includes all power plants that have been owned by IOUs at any moment during our sample period. The analysis compares two competing outcomes: a complete sale of a power plant to any new ownership type (not a partial sale or reduced ownership stake) and a decommissioning of a plant. In Columns (2) to (4), the analysis decomposes the sales outcome into four competing sub-outcomes: sell to PE, sell to institutional investors, sell to foreign corporations, sell to any other new ownership type, such as government or cooperative (not reported, but it is a competing outcome). *IPP ISO Balancing* and *ISO Restructured* are indicators for power plants operating in a deregulated electricity market. Panel B presents the second stage results of an IV model where we instrument the *ISO Restructured* variable with the difference between the average residential and industrial electricity prices in a state over the 1991–1996 period. Online Appendix Table A.4 reports the first stage estimates. We also control for *Climate Concern* percentile ranking and *Renewables Incentives* aggregate index. The specifications include controls for plant capacity, plant age, and fuel-type fixed effects. We cluster standard errors by plant-prime-mover and report standard errors in brackets. *$p < .10$; **$p < .05$; ***$p < .01$.

Event of Interest:	Sell All (1)	Sell to PE (2)	Sell to II (3)	Sell to Fgn (4)	Dec. (5)
#Events of Interest:	656	544	178	67	377
#Competing Events:	377	489	855	966	656
#Total Subjects:	2,767	2,767	2,767	2,767	2,767
Panel A: IPP ISO Balancing Market Deregulation Measure					
IPP ISO Balancing	3.182***	4.639***	2.512***	0.439**	0.986
	[0.345]	[0.599]	[0.530]	[0.141]	[0.129]
Climate Concern	2.406***	2.515***	3.256***	7.691***	1.267
	[0.412]	[0.482]	[1.138]	[4.011]	[0.333]
Renewables Incentives	0.877***	0.894**	1.089	0.833	1.067
	[0.037]	[0.041]	[0.086]	[0.094]	[0.062]
Plant Characteristics	Yes	Yes	Yes	Yes	Yes
Fuel-Type FE	Yes	Yes	Yes	Yes	Yes
Observations	326,312	326,312	326,312	326,312	326,312
Panel B: IV ISO Restructured Market Deregulation Measure					
ISO Restructured	3.414***	3.493***	1.509	2.193	0.501*
	[0.891]	[0.959]	[0.722]	[1.889]	[0.201]
Climate Concern	2.914***	3.654***	4.954***	2.535*	1.701*
	[0.591]	[0.827]	[1.939]	[1.377]	[0.480]
Renewables Incentives	0.840***	0.852***	1.058	0.877	1.069
	[0.036]	[0.041]	[0.087]	[0.097]	[0.061]
Plant Characteristics	Yes	Yes	Yes	Yes	Yes
Fuel-Type FE	Yes	Yes	Yes	Yes	Yes
Observations	326,312	326,312	326,312	326,312	326,312

Table 7: Decommissioning Channel and Market Deregulation

In this table, observations are at the plant-prime-mover-month level and the sample includes only power plants with a capacity of at least 20MW. We present the hazard ratios of a survival analysis using the Cox proportional hazard model. The event of interest is a complete decommissioning of a power plant (not partial retirement of one generator). *#Plants* reports the number of unique plant-prime-mover units included in the survival analysis, while *#Decommissioned* reports the number of unique plant-prime-mover units that are retired by the end of the survival analysis. We measure the ownership by IOUs, PE, institutional investors, and foreign corporations. We also control for the ownership by industry firms, government, cooperatives, and others. *ISO Balancing*, *IPP ISO Balancing*, and *ISO Restructured* are indicators for power plants operating in a deregulated electricity market. In Column (4), we present the second stage results of an IV model where we instrument the *ISO Restructured* variable with the difference between the average residential and industrial electricity prices in a state over the 1991–1996 period. Online Appendix Table A.4 reports the first stage estimates of both IV regressions. We also control for the interactions of *IOUs* ownership with *Climate Concern* percentile ranking and *Renewables Incentives* aggregate index. The specifications include fuel-type and state fixed effects. *ln Plant Capacity* is the natural logarithm of a plant's monthly capacity. *ln Plant Age* is the natural logarithm of plant age in years. We cluster standard errors by plant-prime-mover and report standard errors in brackets. For the IV model, we present the Kleibergen-Paap rk Wald F statistic. *$p < .10$; **$p < .05$; ***$p < .01$.

Decommissioned Power Plants (5,392 Plants; 758 Decommissioned)				
	(1)	(2)	(3)	(4)
IOUs	0.806	0.988	1.095	0.699
	[0.238]	[0.276]	[0.284]	[0.158]
ISO Balancing	0.731*			
	[0.138]			
IOUs × ISO Balancing	1.429**			
	[0.250]			
IPP ISO Balancing		0.871		
		[0.145]		
IOUs × IPP ISO Balancing		1.308		
		[0.265]		
ISO Restructured			1.122	0.907
			[0.286]	[0.252]
IOUs × ISO Restructured			0.993	0.753
			[0.166]	[0.339]
IOUs × Climate Concern	1.289	1.112	1.242	1.863**
	[0.404]	[0.381]	[0.395]	[0.498]
IOUs × Renewables Incentives	1.022	1.023	1.020	1.090
	[0.067]	[0.067]	[0.066]	[0.058]
ln Plant Capacity	0.603***	0.606***	0.606***	0.684***
	[0.023]	[0.023]	[0.023]	[0.025]
ln Plant Age	3.252***	3.240***	3.236***	3.164***
	[0.287]	[0.285]	[0.284]	[0.264]
Other Owners	Yes	Yes	Yes	Yes
Fuel-Type FE	Yes	Yes	Yes	Yes
Plant State FE	Yes	Yes	Yes	
Observations	753,396	753,396	753,396	753,396
K-P F-Stat				233.985
Model	OLS	OLS	OLS	IV

Table 8: Operating Performance

In this table, observations are at the plant-prime-mover-month level and weighted by capacity. In Columns (1) to (4), the dependent variable is the monthly capacity factor, which is the ratio of net electricity generation in MWh to nameplate capacity. We winsorize the capacity factor at 0.5% and 99.5%. In Columns (5) to (8), the dependent variable is the monthly heat rate, which is the ratio of fuel consumption in millions of Btu to electricity generation in MWh. We observe the heat rate for fossil fuel and nuclear power plants. We measure the ownership by IOUs, PE, institutional investors, and foreign corporations. We also control for the ownership by industry firms, government, cooperatives, and others. *IPP ISO Balancing* and *ISO Restructured* are indicators for power plants operating in a deregulated electricity market. In Columns (4) and (8), we present the second stage results of an IV model where we instrument the *ISO Restructured* variable with the difference between the average residential and industrial electricity prices in a state over the 1991–1996 period. Online Appendix Table A.4 reports the first stage estimates of the IV regressions. *ln Plant Capacity* is the natural logarithm of a plant's monthly capacity. *ln Plant Age* is the natural logarithm of plant age in years. *Greenfield 1m* is an indicator for the first month when a plant starts operating. *Greenfield 12m* is an indicator for the first 12 months when a plant starts operating. *Decommissioned 1m* is an indicator for the last month when a plant is still operating. *Decommissioned 12m* is an indicator for the last 12 months when a plant is still operating. The specifications include interacted fuel-type, state, and year-month fixed effects. We double cluster standard errors by plant-prime-mover and time, and report standard errors in brackets. For the IV model, we present the Kleibergen-Paap rk Wald F statistic. *$p < .10$; **$p < .05$; ***$p < .01$.

	Capacity Factor Mean Dependent Variable = 0.412				**Heat Rate** Mean Dependent Variable = 11.324			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
IOUs	0.016*		0.086***	0.050**	0.616***		0.184	0.325
	[0.010]		[0.015]	[0.022]	[0.131]		[0.164]	[0.221]
Private Equity		-0.029***				-0.434***		
		[0.011]				[0.150]		
Institutional Investors		0.097***				-1.607***		
		[0.033]				[0.440]		
Foreign Corporations		-0.014				-0.873***		
		[0.013]				[0.232]		
IPP ISO Balancing			0.085***				-0.508**	
			[0.016]				[0.203]	
IOUs × IPP ISO Balancing			-0.108***				0.671***	
			[0.017]				[0.224]	
ISO Restructured				0.057*				-0.478
				[0.033]				[0.318]
IOUs × ISO Restructured				-0.108***				0.449
				[0.038]				[0.361]
ln Plant Capacity	0.019***	0.018***	0.019***	0.022***	-0.373***	-0.373***	-0.373***	-0.389***
	[0.003]	[0.003]	[0.003]	[0.004]	[0.059]	[0.059]	[0.059]	[0.059]
ln Plant Age	-0.109***	-0.110***	-0.108***	-0.105***	1.320***	1.329***	1.312***	1.184***
	[0.006]	[0.006]	[0.006]	[0.006]	[0.099]	[0.098]	[0.099]	[0.090]
Greenfield 1m	-0.169***	-0.169***	-0.170***	-0.166***	1.882***	1.879***	1.885***	1.841***
	[0.011]	[0.011]	[0.011]	[0.011]	[0.653]	[0.650]	[0.654]	[0.587]
Greenfield 12m	-0.141***	-0.141***	-0.142***	-0.122***	1.734***	1.742***	1.739***	1.242***
	[0.011]	[0.011]	[0.011]	[0.012]	[0.207]	[0.207]	[0.208]	[0.215]
Decommissioned 1m	-0.074***	-0.074***	-0.074***	-0.085***	0.486	0.481	0.489	0.250
	[0.017]	[0.017]	[0.017]	[0.016]	[0.453]	[0.454]	[0.454]	[0.446]
Decommissioned 12m	-0.125***	-0.123***	-0.123***	-0.130***	0.477***	0.470***	0.467***	0.508***
	[0.012]	[0.011]	[0.011]	[0.015]	[0.151]	[0.150]	[0.151]	[0.141]
Other Owners	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fuel-State-Year-Month FE	Yes	Yes	Yes		Yes	Yes	Yes	
Fuel-Year-Month FE				Yes				Yes
Observations	1,398,265	1,398,265	1,398,265	1,478,395	590,140	590,140	590,140	664,027
Adjusted R-squared	0.635	0.636	0.638		0.336	0.336	0.336	
K-P F-Stat				199.203				156.032

Table 9: Changes in Ownership and Operating Performance

In Columns (1) and (2), the dependent variable is the monthly capacity factor, which is the ratio of electricity generation to capacity. We winsorize the capacity factor at 0.5% and 99.5%. In Columns (3) and (4), the dependent variable is the monthly heat rate, which is the ratio of fuel consumption to electricity generation. We observe the heat rate for fossil fuel and nuclear power plants. In Panel A, we focus on the subsample of power plants that experienced an ownership change and were sold by IOUs to PE, institutional investors, and foreign corporations. The event window covers 24 months pre and post the ownership change. In Columns (1) and (3) we analyze only the subsample of treated power plants. In Columns (2) and (4), we stack each treated power plant with a matched never-treated power plant that has been always owned by IOUs. We match exactly based on fuel type and prime mover, and nearest neighbor based on plant capacity and age. The control variables include *ln Plant Capacity*, *ln Plant Age*, *Greenfield 1m*, *Greenfield 12m*, *Decommissioned 1m* and *Decommissioned 12m*. The specifications include interacted state and year-month fixed effects, and interacted plant-prime-mover and stacked cohort fixed effects. We double cluster standard errors by plant-prime-mover-cohort and time, and report standard errors in brackets. In Panel B, we analyze only the subsample of newly created power plants by IOUs, PE, institutional investors, and foreign corporations during the 2005–2020 period. Columns (1) and (3) examine the operating performance of all new plants, while Columns (2) and (4) create a matched subsample. In this panel, *IOUs* indicates whether the first-ever owner of a power plant was an IOU. We double cluster standard errors by plant-prime-mover and time, and report standard errors in brackets. *$p < .10$; **$p < .05$; ***$p < .01$.

	Capacity Factor		**Heat Rate**	
	(1)	(2)	(3)	(4)
Panel A: Plants Sold by IOUs				
	Only Treated	Matched DID	Only Treated	Matched DID
Post × Treated	-0.005	0.000	-0.309*	-0.441**
	[0.006]	[0.006]	[0.181]	[0.176]
Controls	Yes	Yes	Yes	Yes
State-Year-Month FE	Yes	Yes	Yes	Yes
Plant-Prime-Mover FE	Yes		Yes	
Fuel Type FE	Yes		Yes	
Plant-Prime-Mover × Cohort FE		Yes		Yes
Year-Month × Cohort FE		Yes		Yes
Observations	54,064	87,003	19,822	37,952
Adjusted R-squared	0.805	0.812	0.738	0.733
Panel B: Plants Created by IOUs and New Entrants				
	All	Match	All	Match
IOUs	0.008	0.006	0.387*	0.666**
	[0.006]	[0.007]	[0.224]	[0.295]
Controls	Yes	Yes	Yes	Yes
State-Year-Month FE	Yes	Yes	Yes	Yes
Fuel Type FE	Yes	Yes	Yes	Yes
Observations	197,645	86,898	30,173	8,935
Adjusted R-squared	0.459	0.406	0.189	0.236

Online Appendix

The Shifting Finance of Electricity Generation

A.1 Power Plants and Electricity Markets

A.1.1 Electricity Production, Imports, and Exports

The percentage of electricity generated by power plants owned by domestic investor-owned utilities (IOUs) declined from 70% in 2005 to 54% in 2020. Private equity (PE), institutional investors, and foreign corporations replace domestic IOUs as their share jointly increases from 7% in 2005 to 24% in 2020. The generation share of governments, cooperatives, and industry firms remains constant. The ownership changes while the total electricity production remains constant. Online Appendix Figure A.1 Panel A shows that the U.S. produced around 4.1 trillion kWh of electricity in 2005 and the total output has remained constant over our sample period. Panel B plots the total imports and exports of electricity, which also remain stable over our analysis and are economically marginal as they account for less than 1.5% of the U.S. electricity market.

A.1.2 Power Plant Summary Statistics

In our main analysis, we present weighted statistics by power plant capacity, as the sample contains many small power plants that contribute very little to overall generation. One limitation of capacity-weighting is that power plants that use fuels with lower capacity factors receive disproportionately higher weights than power plants that use fuels with higher capacity factors. In our greenfield analysis, we rely primarily on capacity weights with fuel-type-state-time fixed effects, but we also estimate tests without weighting on the subsample of power plants with a capacity of at least 20MW. Online Appendix Table A.1 reports summary statistics without weighting the power plants and focuses only on the subsample of power plants with a capacity of at least 20MW.

This subsample of larger plants also shows substantial construction of new plants and decommissioning of old plants. Out of 5,392 unique plants, 1,883 are new greenfield plants, and their first 12 months of operation account for 2.8% of the sample. In this subsample, 793 power plants were shut down, and their last 12 months of operation account for 1.2% of the sample.

A.1.3 Regulation of Electricity Markets

Online Appendix Table A.2 shows how many power plants in each state operate under a deregulated wholesale market. *ISO Balancing* is our broadest measure of market deregulation, and it is an indicator for power plants that operate in a wholesale market administered by an Independent System Operator (ISO) as a balancing authority. This table shows that the *ISO Balancing* measure also covers plants located in areas that did not restructure their utilities but agreed to operate in a competitive wholesale market. Thus, this measure includes also many plants that are still subject to rate-of-return regulation, especially in MISO and SPP. *IPP ISO Balancing* is our main measure of market deregulation, and it captures only power plants that participate in an ISO Balancing market and are owned by an independent power producer (IPP). This measure captures only IPPs that operate under a market-based pricing model and excludes all plants owned by regulated electric utilities that operate under a cost-of-service model. *ISO Restructured* is an alternative more restrictive definition of market deregulation. It captures power plants that participate in a wholesale market administered by an ISO balancing authority and are located in areas with restructured electric utilities. In addition to having restructured utilities, the *ISO Restructured* wholesale markets typically also offer a retail choice to residential or business customers. The overlap between the *IPP ISO Balancing* and *ISO Restructured* measures is substantial and 27% of plants in the sample on a capacity-weighted basis are classified as deregulated under both measures.

Importantly for our analysis, the ISO markets were established before our sample period, mostly around 2000, and before the wind and solar technologies became competitive as well as before the shale gas revolution. This timeline reduces concerns regarding reverse causality, specifically the alternative hypothesis that ISOs were created to stimulate the adoption of new technologies. In Online Appendix Table

A.3, we examine whether state-level energy resources, economic factors, political factors, and electricity prices predict deregulation. Using the Cox proportional hazard model, We estimate a survival analysis on a state level with two dependent variables. In Columns (1) to (4), the event of interest is the year when a deregulated ISO-balancing wholesale market becomes effective and starts operating. In Columns (5) to (8), the event of interest is the year when the state legislation completes the approval and formation of a deregulated ISO-restructured wholesale market.

We find that the decision to establish ISO balancing markets is unrelated to variations in state-level solar and wind energy potential. If anything, the estimates on the approval of ISO-restructured markets suggest that states with higher wind or solar potential scaled by the amount of electricity consumption were less likely to restructure the local utilities and deregulate the electricity markets. The decision to deregulate the electricity markets is also unrelated to the production of natural gas or coal in a state normalized by the amount of electricity consumption. In line with prior research, the main factor that predicts wholesale market deregulation is not the average electricity price in a state, but rather the difference between the average electricity price in the residential sector and the average electricity price in the industrial sector (White, 1996; Joskow, 1997). We document that states with a significantly higher average electricity price in the residential sector than the average electricity price in the industrial sector are more likely to establish an ISO-balancing wholesale market and restructure the local electric utilities. Overall, we show that state-level natural resources, economic, and political factors do not predict electricity market deregulation.

A.1.4 Market Deregulation and Instrumental Variable Methodology

Our identification of the effect of deregulation on the creation of new plants and ownership changes relies on the assumption that power plants in deregulated and traditional markets would have followed parallel trends absent the deregulation conditional on observed plant characteristics. We address the possibility of omitted variables bias using an instrumental variables (IV) approach. Since the difference between retail and industrial electricity prices on a state level is the main predictor of deregulation (White (1996), Joskow (1997)), we use it as an instrumental variable for deregulation. The IV is the average residential-industrial price difference *ResidIndPD* on a state level over the 1991–1996 period. We construct the IV over the 1991–1996 period to address the staggered restructuring of electricity markets. The first ISO restructured market, PJM Interconnection, started functioning as a competitive wholesale electricity market in 1997, so the IV is measured before any plants operated in a deregulated market. We use the difference between retail and industrial electricity prices to instrument for power plants operating in *ISO Restructured* markets, which is our more restrictive measure of wholesale market deregulation. The ISO restructurings had to be approved by state legislative bodies and were completed at the end of the 1990s, while some ISO balancing markets (but not restructured), such as MISO and SPP, were formed later without state legislative approval.

This is the first-stage regression that we estimate to instrument the *ISO Restructured* markets using the average residential-industrial price difference *ResidIndPD*:

$$ISO_{i,t} = \beta_1 ResidIndPD_i + \gamma' Z_{i,t} + \delta_{ft} + \varepsilon_{i,t}. \tag{13}$$

In some specifications, our analysis examines the baseline effect of ISO Restructured and an interaction term of IOUs and ISO Restructured, so we estimate two first-stage regressions to instrument for both variables:

$$ISO_{i,t} = \beta_1 ResidIndPD_i + \beta_2 IOU_{i,t} \times ResidIndPD_i + \beta_3 IOU_{i,t} + \gamma' Z_{i,t} + \delta_{ft} + \varepsilon_{i,t}, \tag{14}$$

$$IOU_{i,t} \times ISO_{i,t} = \beta_1 ResidIndPD_i + \beta_2 IOU_{i,t} \times ResidIndPD_i + \beta_3 IOU_{i,t} + \gamma' Z_{i,t} + \delta_{ft} + \varepsilon_{i,t}. \tag{15}$$

In the IV specifications, we include only interacted fixed effects on a fuel-year-month level, as the IV does not vary within a state. The second stage uses the predicted values of both variables.

Online Appendix Table A.4 presents the coefficient estimates of the first-stage regressions for the IV specification each time it is used in the paper. The difference between retail and industrial electricity prices on a state level over the 1991–1996 period strongly predicts whether a power plant i will operate in an ISO-restructured market in period t. The first-stage F-statistics are mostly well above 100 and always pass tests for weak instruments.

A.1.5 Renewable Policy Incentives

We use the Database of State Incentives for Renewables & Efficiency (DSIRE) from the N.C. Clean Energy Technology Center to collect information on the policy incentives introduced by different states to stimulate the transition to renewable energy sources. We split the policy initiatives into three types of tax incentives: Renewables Corporate Tax, Renewables Property Tax, and Renewables Sales Tax; and two types of production incentives: Renewables Production and Renewables Tariffs. Renewables Corporate Tax Incentives capture programs that provide a corporate tax credit, corporate tax deduction, and corporate depreciation. Renewables Property Taxes capture programs offering property tax exemption or reduction. Renewables Sales Taxes incentives offer an exemption or reduction from sales and use tax for equipment, generation, etc. Renewables Production incentives offer monetary compensation per KWh that can differ by fuel type and plant capacity. Renewables Tariffs incentives capture primarily feed-in tariffs, which offer long-term contracts with an above-market price to renewable energy producers. In our analysis, we include a *Renewables Incentives* index, which aggregates the three tax indicators and the two production indicators. Online Appendix Table A.5 presents the average value of the five indicators and aggregate renewables incentives index by state over the 2005–2020 period. The index varies from 0.00 in Arkansas to 3.91 incentive types in Vermont.

Figure A.1: Total U.S. Electricity Market

Panel A presents the total U.S. electricity generation over the 2005–2021 period. The data is based on the Energy Information Administration (EIA) Monthly Energy Review Table 7.2a and includes generation from power plants with at least 1 MW electric generation capacity. Panel B shows the total U.S. electricity imports and electricity exports to Canada and Mexico over the 2011–2021 period. The data is based on the Energy Information Administration (EIA) Table 2.14. (Sources: 2016–2021, U.S. Energy Information Administration, Form EIA-111, Quarterly Electricity Imports and Exports Report; 2006–2015 data, National Energy Board of Canada; FERC 714, Annual Electric Balancing Authority Area and Planning Report; California Energy Commission; and EIA estimates.)

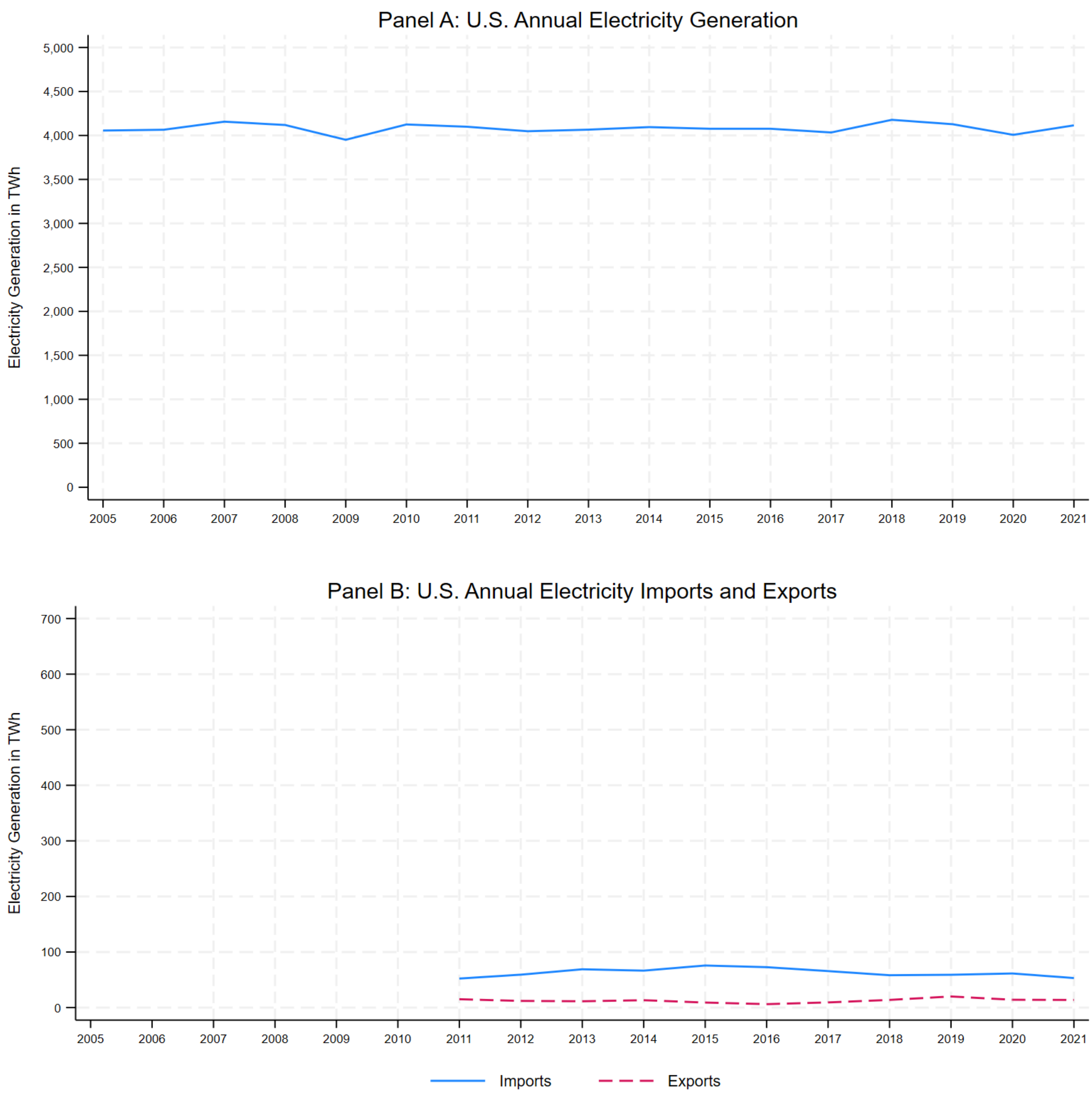


Table A.1: EIA Power Plants (Not Weighted Observations)

Robustness statistics of Table 1: We do not weight observations by power plant nameplate capacity, but we limit attention to the subsample of power plants with a nameplate capacity of at least 20MW.

The table presents summary statistics on a plant-prime-mover-month level for all power plants together as well as separately for the main fuel types: natural gas, coal, nuclear, hydro, wind, and solar plants. The sample includes only power plants with a nameplate capacity of at least 20MW. Panel B reports statistics for the power plant characteristics: *Capacity*, *Capacity Factor*, *Heat Rate*, *Age*, *Greenfield*, and *Decommissioned*. Panel C reports the average ownership by the eight categories in percent. If multiple ownership types own a power plant, we divide the ownership equally across the ownership types. Panel D presents statistics on electricity markets. *ISO Balancing* is an indicator for power plants operating in an ISO-balancing wholesale market. *IPP ISO Balancing* is an indicator for power plants that participate in an ISO-balancing market and are owned by independent power producers. *ISO Restructured* is an indicator for power plants that participate in an ISO balancing wholesale market and are located in areas with restructured utilities. *ResidIndPD* is the difference between the average residential and industrial electricity prices in a state over the 1991–1996 period. *Climate Concern* is the percentile ranking of the state where the plant is located based on the percentage of the state population who think that global warming is happening. *Renewables Incentives* is an aggregate index of three indicators if a state has corporate tax, property tax, and sales tax incentives for renewable energy as well as two indicators if a state has production or feed-in tariffs incentives for renewable energy.

	All	**NatGas**	**Coal**	**Nuclear**	**Hydro**	**Wind**	**Solar**
Panel A: Power Plants Sample							
# Unique Plants	4,455	1,960	651	66	457	879	502
# Unique Plants-Prime-Mover	5,392	2,791	728	66	457	879	502
# Unique Greenfield	1,883	514	35	0	5	777	501
# Unique Decommissioned	793	528	246	10	5	23	1
Observations	753,396	420,705	102,606	12,215	86,146	87,828	21,062
Panel B: Power Plant Characteristics							
Capacity (GWh)	0.285	0.257	0.635	1.689	0.163	0.115	0.063
Capacity Factor	0.318	0.263	0.478	0.857	0.373	0.321	0.257
Heat Rate		11.983	10.768	10.459			
Age (Years)	28.533	22.900	42.956	33.668	61.290	7.007	2.701
Greenfield	0.028	0.015	0.003	0	0.001	0.1	0.251
Decommissioned	0.012	0.013	0.028	0.009	0.001	0.003	0.001
Panel C: Power Plant Ownership							
IOUs	0.420	0.392	0.505	0.864	0.345	0.414	0.533
Private Equity (PE)	0.145	0.161	0.075	0.013	0.074	0.244	0.276
Institutional Investors	0.016	0.018	0.003	0.000	0.006	0.039	0.055
Foreign Corporations	0.074	0.053	0.022	0.016	0.031	0.263	0.101
Industry	0.069	0.087	0.137	0.000	0.013	0.002	0.011
Government	0.198	0.193	0.170	0.106	0.512	0.015	0.002
Cooperative	0.051	0.067	0.071	0.000	0.020	0.009	0.004
Other	0.026	0.029	0.017	0.000	0.000	0.015	0.017
Panel D: Wholesale Electricity Markets							
ISO Balancing	0.637	0.668	0.642	0.701	0.400	0.774	0.555
IPP ISO Balancing	0.402	0.422	0.306	0.476	0.116	0.687	0.519
ISO Restructured	0.315	0.350	0.317	0.489	0.137	0.312	0.097
ResidIndPD	9.935	10.189	9.514	10.507	9.134	9.877	10.189
Climate Concern	0.572	0.592	0.442	0.560	0.573	0.534	0.738
Renewables Incentives	2.216	2.223	2.066	2.107	2.033	2.576	2.515

Table A.2: Regulatory Policy by State

We present the number of plant-prime-mover-month observations by state based on the electricity market regulatory status. *ISO Balancing* is an indicator for power plants that participate in a wholesale market administered by an Independent System Operator. *IPP ISO Balancing* is an indicator for power plants that participate in an ISO balancing market and are owned by independent power producers. *ISO Restructured* is an indicator for power plants that participate in an ISO balancing wholesale market and are located in areas with restructured electric utilities. In *traditional* markets, vertically integrated local electric utilities own power plants generating electricity as well as the transmission system and delivery network.

State	ISO Balancing	IPP ISO Balancing	ISO Restructured	Traditional	Total Plants
Alabama	0	0	0	18,554	18,554
Alaska	0	0	0	28,227	28,227
Arizona	261	261	0	22,194	22,455
Arkansas	9,226	3,062	0	3,120	12,346
California	174,277	132,665	0	36,161	210,438
Colorado	162	162	0	30,523	30,685
Connecticut	17,951	15,659	17,951	0	17,951
Delaware	4,988	4,611	4,988	0	4,988
District of Columbia	503	491	503	0	503
Florida	0	0	0	41,808	41,808
Georgia	0	0	0	29,415	29,415
Hawaii	0	0	0	11,976	11,976
Idaho	0	0	0	22,249	22,249
Illinois	40,842	28,855	40,842	893	41,735
Indiana	24,336	10,340	0	408	24,744
Iowa	37,500	13,524	0	5,039	42,539
Kansas	23,031	4,168	0	3,093	26,124
Kentucky	3,298	693	0	6,414	9,712
Louisiana	17,677	11,165	0	2,654	20,331
Maine	18,323	17,883	18,323	1,713	20,036
Maryland	15,587	14,449	15,587	0	15,587
Massachusetts	47,328	40,584	47,328	0	47,328
Michigan	46,433	19,542	46,433	808	47,241
Minnesota	59,905	35,626	0	3,054	62,959
Mississippi	4,787	895	0	7,010	11,797
Missouri	17,677	3,570	0	8,456	26,133
Montana	1,102	157	0	7,815	8,917
Nebraska	14,593	2,490	0	4,900	19,493
Nevada	984	720	0	14,739	15,723
New Hampshire	12,712	9,736	12,712	0	12,712
New Jersey	38,561	36,123	38,561	0	38,561
New Mexico	3,502	2,472	0	11,258	14,760
New York	82,050	68,223	82,050	0	82,050
North Carolina	7,178	5,658	0	56,348	63,526
North Dakota	7,884	3,572	0	563	8,447
Ohio	30,422	14,438	30,422	440	30,862
Oklahoma	17,363	6,829	0	3,193	20,556
Oregon	0	0	0	27,798	27,798
Pennsylvania	42,263	41,603	42,263	192	42,455
Rhode Island	5,590	5,398	5,590	0	5,590
South Carolina	0	0	0	21,841	21,841
South Dakota	3,236	1,202	0	3,262	6,498
Tennessee	368	368	0	12,648	13,016
Texas	84,462	66,013	68,936	3,745	88,207
Utah	0	0	0	15,445	15,445
Vermont	14,051	5,268	0	0	14,051
Virginia	27,395	11,985	23,575	889	28,284
Washington	0	0	0	26,090	26,090
West Virginia	5,970	3,196	0	927	6,897
Wisconsin	36,445	13,965	0	2,066	38,511
Wyoming	0	0	0	11,195	11,195
Total	1,000,223	657,621	496,064	509,123	1,509,346

Table A.3: Predicting Deregulation by State

In this table, observations are at the state-year level and the sample covers the 1991–2010 period. We start in 1991 as the first event of approved market deregulation is in 1993, and we stop in 2010 as the last event of effective deregulation is in 2009. We present the hazard ratios of a survival analysis using the Cox proportional hazard model. In Columns (1) to (4), the event of interest is the year when a deregulated ISO-balancing wholesale market becomes effective and starts operating. In Columns (5) to (8), the event of interest is the year when the state legislation completes the approval and formation of a deregulated ISO-restructured wholesale market. The *WindPotential* measures the wind capacity potential in MW at 80 meters and aggregates the capacity across the ten wind TRG classes. The data is provided by the AWS Truepower and National Renewable Energy Laboratory. For AK, DC, and HI, we append the data on wind capacity potential using information from the NREL U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis. The *SolarPotential* measures the urban and rural utility-scale PV solar capacity in GWh and comes from the NREL U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis. *NatGasProduction* is the natural gas dry production in million cubic feet, provided by the EIA Natural Gas Gross Withdrawals and Production data series. The *CoalProduction* measures the aggregate annual coal production in short tons and is reported by the EIA and U.S. Mine Safety and Health Administration. We scale the wind potential, solar potential, natural gas production, and coal production variables by the total electricity consumption (electricity sales to ultimate customers), provided by the EIA State Energy Data System (SEDS). *Electricity Price* is the average electricity price of all sectors in dollars per million Btu. *ResidIndPD* is the difference between the average electricity price in the residential sector and the average electricity price in the industrial sector. The data on average prices comes from the EIA State Energy Data System (SEDS). The state GDP per capita is from the Bureau of Economic Analysis. The annual unemployment rate is the average of the monthly unemployment rates by state, reported by the Bureau of Labor Statistics. *Democratic Control* and *Republican Control* are indicator variables capturing whether both legislative branch levels (house and senate) are controlled by the Democrats or Republicans (the omitted category is split control). We cluster standard errors by state, and report standard errors in brackets. $^*p < .10$; $^{**}p < .05$; $^{***}p < .01$.

	ISO Balancing Effective				**ISO Restructured Approved**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
WindPotential / ElecConsumption	0.975	0.976			0.716**	0.733**		
	[0.017]	[0.018]			[0.105]	[0.110]		
SolarPotential / ElecConsumption			0.999	0.999			0.984**	0.987**
			[0.001]	[0.001]			[0.007]	[0.006]
NatGasProduction / ElecConsumption	0.993	0.994	0.990	0.989	0.992	1.010	0.999	1.014
	[0.011]	[0.012]	[0.012]	[0.013]	[0.021]	[0.022]	[0.019]	[0.021]
CoalProduction / ElecConsumption	0.974	0.969	0.961	0.960	0.938	1.251	0.734	0.994
	[0.056]	[0.065]	[0.062]	[0.069]	[0.200]	[0.247]	[0.174]	[0.146]
Electricity Price	0.995	0.983	0.995	0.982	1.029	1.059	0.999	1.038
	[0.030]	[0.034]	[0.030]	[0.033]	[0.047]	[0.059]	[0.046]	[0.060]
ResidIndPD	1.112***	1.124**	1.115***	1.130**	1.273***	1.288**	1.268***	1.264**
	[0.045]	[0.054]	[0.045]	[0.055]	[0.096]	[0.164]	[0.089]	[0.142]
GDP Per Capita		1.016***		1.016***		1.024***		1.023***
		[0.005]		[0.005]		[0.008]		[0.008]
Unemployment Rate		0.892		0.898		0.707		0.749
		[0.136]		[0.134]		[0.183]		[0.195]
Democratic Control		0.923		0.996		0.754		0.626
		[0.392]		[0.422]		[0.734]		[0.540]
Republican Control		0.720		0.724		2.095		1.727
		[0.268]		[0.274]		[1.472]		[1.181]
Observations	766	766	766	766	814	814	814	814

Table A.4: First-Stage Results of the IV Specifications

We present the first-stage estimates of the multiple IV specifications used throughout the paper.

We instrument the *ISO Restructured* variable with the difference between the average residential and industrial electricity prices in a state over the 1991–1996 period (*ResidIndPD*). Where an interaction term of IOU ownership and ISO restructured markets is included, we instrument the *ISO Restructured* and *IOUs* × *ISO Restructured* variables with *ResidIndPD* and the interaction term *IOUs* × *ResidIndPD*. The last row presents the Kleibergen-Paap rk Wald F statistic, which tests for weak instruments.

	Table 5 Column 4 (1)	Table 6 Panel B (2)	Table 7 Column 4 (3)	Table 8 Column 4 (4)	Table 8 Column 8 (5)
Panel A: First Stage Results for ISO Restructured					
ResidIndPD	0.062***	0.056***	0.058***	0.063***	0.062***
	[0.003]	[0.003]	[0.002]	[0.003]	[0.004]
IOUs × ResidIndPD	0.010*		0.001	0.023***	0.026***
	[0.006]		[0.003]	[0.005]	[0.006]
Controls	Yes	Yes	Yes	Yes	Yes
Observations	1,492,665	326,312	753,396	1,478,395	881,809
Adjusted R-squared	0.351	0.236	0.277	0.342	0.327
Panel B: First Stage Results for IOUs × ISO Restructured					
ResidIndPD	-0.001		-0.002***	-0.002	-0.002
	[0.001]		[0.000]	[0.001]	[0.001]
IOUs × ResidIndPD	0.074***		0.061***	0.089***	0.091***
	[0.005]		[0.003]	[0.005]	[0.005]
Controls	Yes		Yes	Yes	Yes
Observations	1,492,665		753,396	1,478,395	881,809
Adjusted R-squared	0.436		0.368	0.424	0.421
K-P rk F-Stat	94.584	408.096	233.985	199.203	156.032

Table A.5: Renewable Policy Index by State

We use the Database of State Incentives for Renewables & Efficiency to collect information on the renewable policy incentives by state-year-month. We split the policy initiatives into three types of tax incentives: Corporate Tax, Property Tax, and Sales Tax; and two types of production incentives: Production and Tariffs. For each type of incentive, we create an indicator variable equal to one if a state has at least one incentive in that category in a given month. The table presents the average values of these indicators over the 2005–2020 period by state. In our analysis, we include a *Renewables Incentives* index, which aggregates the three tax indicators and the two production indicators.

State	Corporate Tax	Property Tax	Sales Tax	Production	Tariffs	Renewables Incentives
Alaska	0.00	0.00	0.00	1.00	0.00	1.00
Alabama	0.00	0.00	0.00	0.62	0.52	1.14
Arkansas	0.00	0.00	0.00	0.00	0.00	0.00
Arizona	0.94	1.00	1.00	0.00	0.00	2.94
California	0.06	0.00	0.19	1.00	0.90	2.15
Colorado	0.37	0.84	0.91	0.93	0.00	3.04
Connecticut	0.00	0.00	0.84	0.49	0.00	1.34
DC	0.00	0.53	0.00	0.49	0.00	1.03
Delaware	0.00	0.00	0.00	0.97	0.00	0.97
Florida	0.62	0.78	1.00	0.30	0.00	2.70
Georgia	0.40	0.00	0.00	0.58	0.00	0.98
Hawaii	1.00	0.70	0.00	0.49	0.71	2.91
Iowa	1.00	1.00	1.00	0.00	0.56	3.56
Idaho	0.00	0.81	0.98	0.00	0.00	1.80
Illinois	0.00	0.88	0.72	0.65	0.00	2.24
Indiana	0.00	0.68	0.00	0.67	0.36	1.71
Kansas	0.31	1.00	0.00	0.00	0.00	1.31
Kentucky	0.81	0.00	0.81	0.62	0.00	2.24
Louisiana	0.62	0.00	0.00	0.00	0.00	0.62
Massachusetts	1.00	1.00	0.00	1.00	0.00	3.00
Maryland	0.87	1.00	0.78	0.49	0.00	3.15
Maine	0.00	0.05	0.00	0.58	0.00	0.63
Michigan	0.00	1.00	0.00	0.71	0.37	2.08
Minnesota	0.00	1.00	1.00	0.93	0.48	3.41
Missouri	0.00	0.59	0.00	0.00	0.00	0.59
Mississippi	0.00	0.00	0.00	0.62	0.38	0.99
Montana	0.69	1.00	0.00	0.00	0.00	1.69
North Carolina	0.68	0.78	0.00	0.98	0.00	2.44
North Dakota	0.62	1.00	0.34	0.00	0.00	1.96
Nebraska	0.88	0.67	0.83	0.00	0.00	2.38
New Hampshire	0.00	1.00	0.00	0.00	0.00	1.00
New Jersey	0.00	0.77	1.00	1.00	0.00	2.77
New Mexico	1.00	0.69	0.84	0.67	0.00	3.20
Nevada	0.00	1.00	0.75	0.93	0.00	2.68
New York	0.37	1.00	0.96	0.07	0.21	2.61
Ohio	0.31	1.00	1.00	0.71	0.00	3.03
Oklahoma	1.00	0.38	0.00	0.00	0.00	1.38
Oregon	0.97	0.66	0.00	0.99	0.00	2.63
Pennsylvania	0.00	0.88	0.00	0.49	0.00	1.37
Rhode Island	0.63	1.00	1.00	0.60	0.00	3.23
South Carolina	0.94	0.00	0.00	0.81	0.00	1.75
South Dakota	0.00	0.84	0.67	0.00	0.00	1.51
Tennessee	0.00	1.00	0.66	0.58	0.00	2.24
Texas	1.00	1.00	0.00	0.66	0.52	3.18
Utah	1.00	0.00	1.00	0.00	0.00	2.00
Virginia	0.00	1.00	0.00	0.62	0.00	1.62
Vermont	0.20	1.00	1.00	0.71	1.00	3.91
Washington	0.00	0.00	0.72	0.96	0.90	2.58
Wisconsin	0.00	0.00	1.00	0.89	0.00	1.89
West Virginia	1.00	1.00	0.00	0.00	0.00	2.00
Wyoming	0.00	0.00	1.00	0.00	0.00	1.00

A.2 The Channels of Ownership Changes

We find that PE and foreign listed corporations are significantly more likely than IOUs to create new power plants and their willingness to finance the capital expenditures to adopt new innovative technologies contributes significantly to the changing ownership structure. Online Appendix Table A.6 shows that our results are robust to using logit specifications instead of pooled OLS. However, we rely more on the OLS specification as the weighted coefficients are economically more relevant for the greenfield analysis, and they include a more saturated set of fixed effects.

In Online Appendix Table A.7, we show that the results are not driven by a few large newly created power plants (we also do not include all power plants to avoid that the results are driven by micro solar plants). The unconditional baseline probability in this unweighted subsample equals 2.77% as compared to 1.63% in the weighted broad sample, which shows that the newly created power plants tend to be on average smaller than the existing power plants. The results confirm that IOUs are less likely to create new power plants than PE and foreign corporations.

In the competing risks analysis in Table 3, we define the sales and decommissioning events of interest based on the final outcome in the dataset. For a small number of power plants, we observe multiple outcomes, such as a plant first being sold by an IOU to a PE firm, later sold back to an IOU, and finally decommissioned by an IOU. In Online Appendix Table A.8, we show that our results and conclusions are robust to defining the events of interest based on the first outcome instead of the last outcome during the sample period. This robustness test by design has fewer decommissioning events and more sales events, but our results on the relation between sales and the two leakage proxies remain the same. We confirm that the sales channel is highly relevant, but it explains only part of the ownership transitions and does not have a substantial effect on plants using new renewable technologies or coal plants using older technologies.

When analyzing the decommissioning channel, we rely primarily on Cox proportional hazard models. In Online Appendix Table A.9, we provide robustness analysis using OLS, defining a dependent variable that equals one for the last 12 months of the plant's operation. These specifications allow for weighting the observations by plant capacity and include fully interacted fuel-type, state, and year-month fixed effects. In line with the hazard results, PE has a similar probability of retiring a power plant as IOUs, while institutional investors and foreign corporations have a significantly lower probability of decommissioning a power plant.

Table A.6: Ownership of Greenfield Power Plants (Logit Specifications)

Robustness check of Table 2: We use logit specifications and do not weight observations by power plant nameplate capacity, but we limit attention to the subsample of power plants with a nameplate capacity of at least 20MW.

In this table, observations are at the plant-prime-mover-month level and the sample includes only power plants with a nameplate capacity of at least 20MW. The dependent variable captures greenfield power plants and equals one for the first 12 months of plant operation. We measure the ownership by domestic publicly listed investor-owned utilities (*IOUs*), private equity, institutional investors, and foreign corporations. We also control for the ownership by industry firms, government, cooperatives, and others. The specifications include fuel-type, state, and year-month fixed effects. We double cluster standard errors by plant-prime-mover and time, and report standard errors in brackets. *$p < .10$; **$p < .05$; ***$p < .01$.

	All Plants		**Solar & Wind**		**Natural Gas**	
	(1)	(2)	(3)	(4)	(5)	(6)
Unconditional Prob.	2.77%	2.77%	12.90%	12.90%	1.37%	1.37%
IOUs	-0.829***		-3.568***		-0.376**	
	[0.141]		[0.793]		[0.172]	
Private Equity		1.073***		4.552***		0.647***
		[0.169]		[0.926]		[0.187]
Institutional Investors		-1.011*		-3.781		-0.878
		[0.540]		[2.734]		[0.770]
Foreign Corporations		0.699***		3.219***		-0.365
		[0.180]		[0.993]		[0.340]
ln Plant Capacity	0.774***	0.781***	4.736***	4.806***	0.457***	0.459***
	[0.080]	[0.080]	[0.563]	[0.560]	[0.077]	[0.076]
Other Owners	Yes	Yes	Yes	Yes	Yes	Yes
Fuel FE	Yes	Yes	Yes	Yes	Yes	Yes
Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
State FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	741,003	741,003	108,862	108,862	414,706	414,706

Table A.7: Ownership of Greenfield Power Plants (Not Weighted Observations)

Robustness check of Table 2: We do not weight observations by power plant nameplate capacity, but we limit attention to the subsample of power plants with a nameplate capacity of at least 20MW.

In this table, observations are at the plant-prime-mover-month level and the sample includes only power plants with a nameplate capacity of at least 20MW. The dependent variable captures greenfield power plants and equals one for the first 12 months of plant operation. We measure the ownership by domestic publicly listed investor-owned utilities (*IOUs*), private equity, institutional investors, and foreign corporations. We also control for the ownership by industry firms, government, cooperatives, and others. *ln Plant Capacity* is the natural logarithm of a plant's monthly capacity. The specifications include interacted fuel-type, state, and year-month fixed effects. In Columns (2), (4), and (6), the specifications also include plant-prime-mover fixed effects. We double cluster standard errors by plant-prime-mover and time, and report standard errors in brackets. $^{*}p < .10$; $^{**}p < .05$; $^{***}p < .01$.

	All Plants		**Solar & Wind**		**Natural Gas**	
	(1)	(2)	(3)	(4)	(5)	(6)
Unconditional Prob.	2.77%	2.77%	12.90%	12.90%	1.37%	1.37%
IOUs	-1.405***	-2.263***	-3.678***	-11.959***	-0.324	-0.878***
	[0.251]	[0.347]	[0.757]	[2.023]	[0.203]	[0.267]
ln Plant Capacity	0.718***		4.378***		0.508***	
	[0.072]		[0.563]		[0.083]	
Other Owners	Yes	Yes	Yes	Yes	Yes	Yes
Fuel-State-Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Plant FE		Yes		Yes		Yes
Observations	676,260	676,188	107,278	107,209	378,699	378,698
Adjusted R-squared	0.152	0.372	0.166	0.395	0.052	0.251

Table A.8: Competing Risks Model: Sales and Decommissioning of Power Plants

Robustness check of Table 3: For power plants that exhibit multiple outcomes during the sample period (e.g., sold-acquired-sold by IOUs), we define the events of interest based on the first outcome.

Observations are at the plant-prime-mover-month level and the sample includes only power plants with a nameplate capacity of at least 20MW. We present the hazard ratios of a survival analysis using a competing risks model. The sample includes all power plants that have been owned by IOUs at any moment during our sample period. The analysis compares two competing outcomes: a complete sale of a power plant to any new ownership type (not a partial sale or reduced ownership stake) and a decommissioning of a plant. In Columns (3) to (5), the analysis decomposes the sales events into four competing sub-outcomes: sell to PE, sell to II, sell to foreign corporations, sell to any other new ownership type, such as government or cooperative (not reported but it is a competing outcome). *ln Plant Capacity* is the natural logarithm of a plant's monthly capacity. *ln Plant Age* is the natural logarithm of plant age in years. The specifications include fuel-type fixed effects and we present the coefficients for coal, nuclear, hydro, wind, and solar power plants (the omitted category is natural gas plants). We cluster standard errors by plant-prime-mover and report standard errors in brackets. *$p < .10$; **$p < .05$; ***$p < .01$.

Event of Interest:	Sell All (1)	Sell All (2)	Sell to PE (3)	Sell to II (4)	Sell to Fgn (5)	Dec. (6)	Dec. (7)
#Events of Interest:	721	721	604	174	73	367	367
#Competing Events:	367	367	484	914	1,015	721	721
#Total Subjects:	2,767	2,767	2,767	2,767	2,767	2,767	2,767
ln Plant Capacity	0.951	0.956	1.006	0.996	0.723***	0.677***	0.608***
	[0.037]	[0.041]	[0.043]	[0.076]	[0.081]	[0.031]	[0.029]
ln Plant Age	1.186***	1.136***	1.193***	1.234***	1.062	5.505***	5.514***
	[0.042]	[0.044]	[0.045]	[0.078]	[0.112]	[0.884]	[0.951]
Coal	0.316***	0.428***	0.297***	0.124***	0.663	1.764***	1.907***
	[0.055]	[0.081]	[0.055]	[0.059]	[0.294]	[0.256]	[0.281]
Hydro	0.186***	0.230***	0.176***	0.156***	0.087**	0.010***	0.010***
	[0.043]	[0.057]	[0.047]	[0.081]	[0.089]	[0.006]	[0.006]
Nuclear	0.063***	0.052***	0.070***	0.000***	0.000***	1.003	1.222
	[0.045]	[0.038]	[0.051]	[0.000]	[0.000]	[0.364]	[0.472]
Solar	0.161***	0.150***	0.224***	0.149***	0.061**	0.000***	0.000***
	[0.043]	[0.041]	[0.061]	[0.094]	[0.067]	[0.000]	[0.000]
Wind	0.566***	0.695***	0.604***	1.200	0.184***	0.601	0.566
	[0.072]	[0.091]	[0.086]	[0.263]	[0.108]	[0.249]	[0.235]
Fuel-Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Plant State FE		Yes					Yes
Observations	321,117	321,117	321,117	321,117	321,117	321,117	321,117

Table A.9: Ownership of Decommissioned Power Plants

Robustness check of Table 4: We estimate pooled OLS instead of Cox proportional hazard model.

In this table, observations are at the plant-prime-mover-month level and are weighted by power plant nameplate capacity. The dependent variable captures decommissioned power plants and equals one for the last 12 months of plant operation. We measure the ownership by IOUs, private equity, institutional investors, and foreign corporations. We also control for the ownership by industry firms, government, cooperatives, and others. The specifications include interacted fuel-type, state, and year-month fixed effects. In Columns (2), (4), and (6), the specifications also include plant-prime-mover fixed effects. We double cluster standard errors by plant-prime-mover and time, and report standard errors in brackets. $^{*}p < .10$; $^{**}p < .05$; $^{***}p < .01$.

	All Plants		**Coal**		**Natural Gas**	
	(1)	(2)	(3)	(4)	(5)	(6)
Unconditional Prob.	1.03%	1.03%	1.84%	1.84%	0.74%	0.74%
Panel A: Main Variable of Interest – Ownership by IOUs						
IOUs	0.092	0.608	1.522	5.814**	-0.234	-0.360
	[0.212]	[0.458]	[1.066]	[2.378]	[0.221]	[0.284]
ln Plant Capacity	-0.647***		-2.389***		-0.343***	
	[0.077]		[0.281]		[0.112]	
ln Plant Age	1.062***		1.628***		1.088***	
	[0.117]		[0.406]		[0.145]	
Other Owners	Yes	Yes	Yes	Yes	Yes	Yes
Fuel-State-Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Plant FE		Yes		Yes		Yes
Observations	1,410,850	1,410,618	100,407	100,404	463,756	463,750
Adjusted R-squared	0.169	0.302	0.054	0.173	0.024	0.273
Panel B: Main Variables of Interest – Ownership by New Entrants						
Private Equity	0.244	-0.459	-1.169	-7.835***	0.673**	0.851**
	[0.277]	[0.546]	[1.300]	[2.804]	[0.294]	[0.345]
Institutional Investors	-1.055***	-0.885**	1.952	0.920	-1.483***	-1.250***
	[0.229]	[0.393]	[2.616]	[5.158]	[0.308]	[0.476]
Foreign Corporations	-0.698***	-1.070*	-2.469**	-0.634	-0.590**	-0.741*
	[0.205]	[0.613]	[1.119]	[2.563]	[0.236]	[0.443]
ln Plant Capacity	-0.646***		-2.397***		-0.343***	
	[0.077]		[0.280]		[0.111]	
ln Plant Age	1.076***		1.653***		1.107***	
	[0.117]		[0.405]		[0.146]	
Other Owners	Yes	Yes	Yes	Yes	Yes	Yes
Fuel-State-Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Plant FE		Yes		Yes		Yes
Observations	1,410,850	1,410,618	100,407	100,404	463,756	463,750
Adjusted R-squared	0.170	0.302	0.054	0.174	0.025	0.273

A.3 Ownership Changes and Market Deregulation

In terms of economic factors, we focus on market regulation which affects the ability of a power plant to operate and sell electricity. Deregulated markets may attract more capital from new entrants as the wholesale market is not managed by a monopolist utility that is also involved in electricity generation. Figure A.2 Panel A shows that IPPs in deregulated ISO balancing markets attract more capital to adopt new technologies. At the end of 2020, greenfield plants created during our sample period represent 36% of the total installed capacity owned by IPPs in ISO balancing markets and 20% in traditional markets. Panel B shows that this difference is concentrated in renewable power plants. Newly created solar and wind plants represent 22% of the installed capacity in IPP ISO balancing markets and only 7% in traditional markets, and the difference is increasing over time.

Panel C of Figure A.2 focuses on the cumulative hazard rate of decommissioned power plants. We observe that power plants in deregulated IPP ISO balancing markets exhibit a 40% higher decommissioning rate than power plants in regulated traditional markets. The decommissioning rate is 17.3% in IPP ISO balancing markets versus 12.4% in traditional markets. Panel D shows that this effect is driven by differences in fossil fuel plant retirements. In the hazard models, we include interaction terms between the ownership types and market deregulation indicators to examine whether any particular ownership type drives these differences.

We extend the competing risks models by incorporating controls for market deregulation in the specifications. In Table 6, we use the IPP ISO Balancing measure and the instrumented ISO Restructured measure. Online Appendix Table A.10 presents the results with the remaining two deregulation measures: ISO Balancing and ISO Restructured. We confirm that electricity market deregulation influences capital flows from new ownership types, as power plant transactions are more likely to be completed in deregulated markets.

Our results highlight the key role of electricity market deregulation in explaining the ownership changes of power plants. If other economic factors drive these results, they need to affect differently IOUs located in deregulated and traditional markets. In terms of economic factors, we find that the effect of market deregulation on heterogeneity in ownership structures is robust to controlling for climate concerns among the state population, and policy incentives for renewable energy.

In the main analysis, we include an interaction term of IOUs with *Renewable Incentives* index, which aggregates five separate renewable policy indicators. One potential concern is that the aggregate index is broad and only some specific policy measures explain the heterogeneity across ownership types in creating or decommissioning power plants. In Online Appendix Figure A.3, we estimate specifications that include separate interaction terms of IOUs with the three indicators if a state has corporate tax, property tax, and sales tax incentives for renewable energy as well as separate interaction terms of IOUs with the two indicators if a state has production incentives or feed-in tariffs for renewable energy. The specifications in Panel A confirm that IOUs are less likely to own greenfield plants in deregulated markets and these results are robust to controlling separately renewable policy incentives. Panel B presents a similar robustness test for decommissioning of power plants. Our baseline specifications do not find significant and consistent heterogeneity across ownership types in their sensitivity of decommissioning decisions to market deregulation. The robustness test with five separate indicators for renewable policy measures documents similar results.

A.3.1 Comparing the Role of Market Regulation with Other Economic Factors

An alternative hypothesis is that electricity market deregulation correlates with IOU characteristics so these corporate characteristics explain the ownership changes rather than market competitiveness. We consider whether our results on plant creation and decommissioning could be driven by corporate credit ratings or ESG ratings. Under this hypothesis, IOUs with weaker credit ratings are more likely to be financially constrained and might engage in less plant creation or more plant destruction. Firms with higher ESG ratings may favor the creation of solar and wind farms and decommissioning of fossil fuel plants. This hypothesis predicts that only low ESG or low credit rating IOUs would be less likely to create greenfield power plants and the differences should be insignificant for high-ranked IOUs.

Figure 6 shows that across all ESG and credit rating categories, IOUs are less likely to own greenfield plants. Importantly, the interaction effects with market deregulation remain robust and significant in almost all ESG rating and credit rating categories. In Online Appendix Figure A.4, we also find that IOUs of all ESG and credit rating categories are less likely to create new solar and wind plants. The IOUs lack of creation of new natural gas plants is more concentrated in firms with lower ESG ratings (counterintuitively) and lower credit ratings. Online Appendix Figure A.5 finds no variation of interest in the decommissioning rates across the ESG or credit rating categories. To the extent that IOUs are more likely to decommission, there is no specific ESG or credit rating category that is more likely to do it in a robust fashion.

In Online Appendix Table A.11, we add ESG rating, credit rating, and legacy coal assets controls to the competing risks model. We find that the role of market deregulation and plant characteristics in explaining the decisions of IOUs to sell or decommission a power plant is robust to these controls. In addition to confirming our main results, we also find that IOUs with low credit ratings are more likely to decommission power plants.

Figure A.2: Greenfield or Decommissioned Power Plants and Market Deregulation

Panel A presents the cumulative capacity of greenfield power plants installed during our sample period as a percentage of the total generating capacity, while Panel B shows the cumulative capacity of solar and wind greenfield power plants installed during our sample period as a percentage of the total capacity. Panel C presents the cumulative hazard rate of decommissioned power plants, while Panel D shows the cumulative hazard rate of fossil fuel decommissioned power plants. In the hazard figures, observations are weighted by nameplate capacity. We split the power plants by market regulation status using the *IPP ISO Balancing* indicator. *IPP ISO Balancing* is an indicator for power plants of independent power producers that participate in a deregulated wholesale market administered by an Independent System Operator (ISO) as a balancing authority.

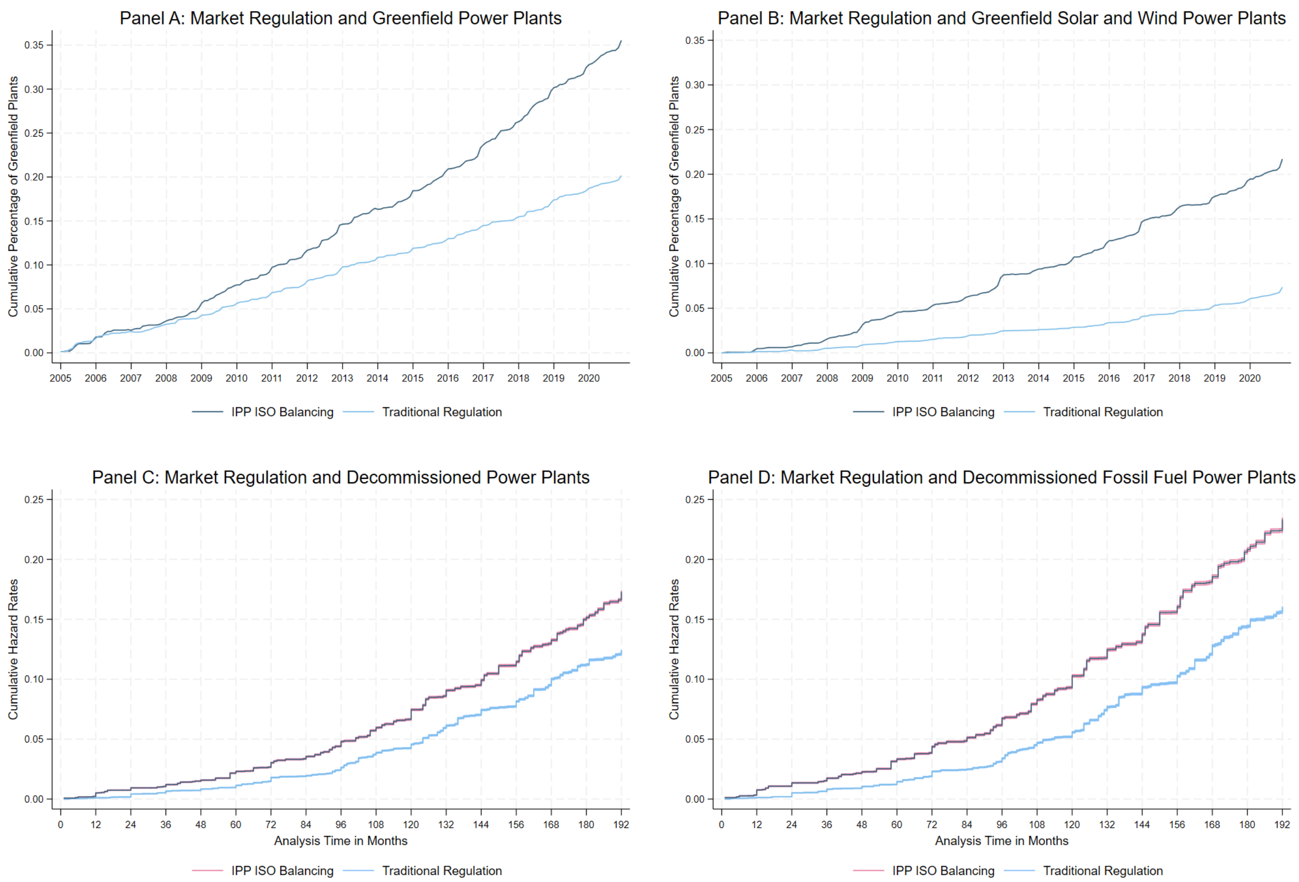


Table A.10: Sales Channel and Market Deregulation

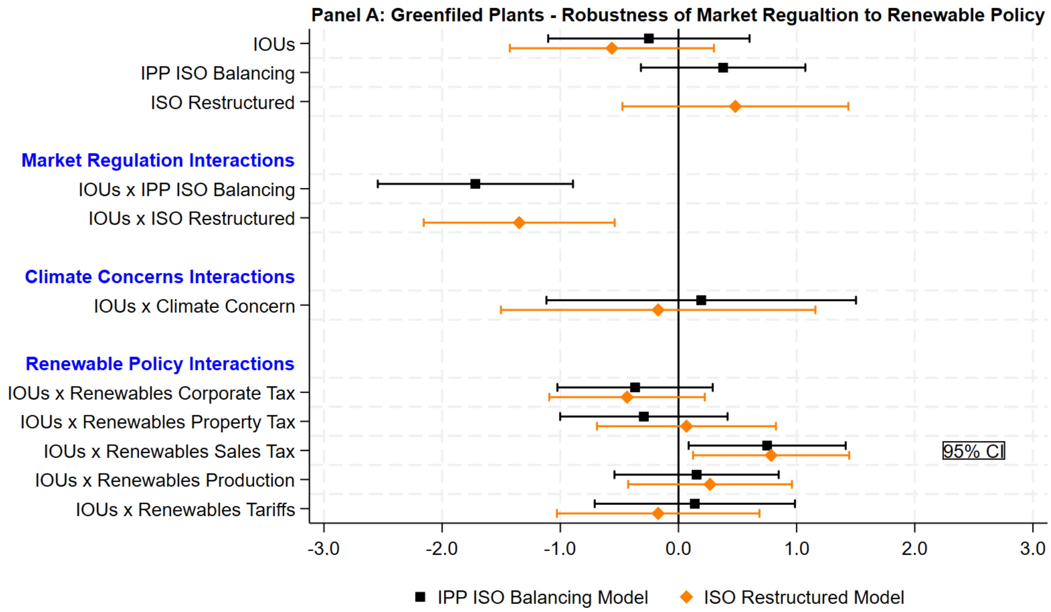
Robustness check of Table 6: We use *ISO Balancing* and *ISO Restructured* are indicators for power plants operating in a deregulated electricity market.

Observations are at the plant-prime-mover-month level and the sample includes only power plants with a nameplate capacity of at least 20MW. We present the hazard ratios of a survival analysis using a competing risks model. The sample includes all power plants that have been owned by IOUs at any moment during our sample period. The analysis compares two competing outcomes: a complete sale of a power plant to any new ownership type (not a partial sale or reduced ownership stake) and a decommissioning of a plant. In Columns (2) to (4), the analysis decomposes the sales events into four competing sub-outcomes: sell to PE, sell to institutional investors, sell to foreign corporations, sell to any other new ownership type, such as government or cooperative (not reported but it is a competing outcome). *ISO Balancing* and *ISO Restructured* are indicators for power plants operating in a deregulated electricity market. We also control for *Climate Concern* percentile ranking and *Renewables Incentives* aggregate index. The specifications include controls for plant capacity, plant age, and fuel-type fixed effects. We cluster standard errors by plant-prime-mover and report standard errors in brackets. *$p < .10$; **$p < .05$; ***$p < .01$.

Event of Interest:	Sell All (1)	Sell to PE (2)	Sell to II (3)	Sell to Fgn (4)	Dec. (5)
#Events of Interest:	656	544	178	67	377
#Competing Events:	377	489	855	966	656
#Total Subjects:	2,767	2,767	2,767	2,767	2,767
Panel A: ISO Balancing Market Deregulation Measure					
ISO Balancing	1.277**	1.602***	1.199	0.492**	0.953
	[0.129]	[0.184]	[0.240]	[0.147]	[0.111]
Climate Concern	4.908***	5.950***	5.770***	4.856***	1.263
	[0.786]	[1.054]	[1.775]	[2.350]	[0.282]
Renewables Incentives	0.859***	0.880***	1.069	0.834	1.065
	[0.038]	[0.043]	[0.090]	[0.096]	[0.060]
Plant Characteristics	Yes	Yes	Yes	Yes	Yes
Fuel-Type FE	Yes	Yes	Yes	Yes	Yes
Observations	326,312	326,312	326,312	326,312	326,312
Panel B: ISO Restructured Market Deregulation Measure					
ISO Restructured	1.874***	2.284***	1.131	0.604	0.796*
	[0.159]	[0.210]	[0.174]	[0.190]	[0.097]
Climate Concern	4.520***	5.632***	5.889***	4.242***	1.467
	[0.776]	[1.115]	[1.815]	[1.749]	[0.349]
Renewables Incentives	0.832***	0.835***	1.056	0.883	1.058
	[0.036]	[0.040]	[0.086]	[0.098]	[0.060]
Plant Characteristics	Yes	Yes	Yes	Yes	Yes
Fuel-Type FE	Yes	Yes	Yes	Yes	Yes
Observations	326,312	326,312	326,312	326,312	326,312

Figure A.3: Renewable Policy Index Split into Five Separate Indicators

In this robustness test, we include five separate interaction terms with the indicators if a state has corporate tax, property tax, sales tax, production, or feed-in tariffs incentives for renewable energy instead of including an interaction term of IOUs with the aggregate *Renewable Incentives* index. In Panel A, the dependent variable captures greenfield power plants and we present the coefficient estimates of three specifications that replicate Columns (4) and (5) of Table 2. Panel B presents the coefficient estimates from Cox hazard model specifications that estimate survival analysis on power plant decommissioning events and replicate Columns (4) and (5) of Table 4.



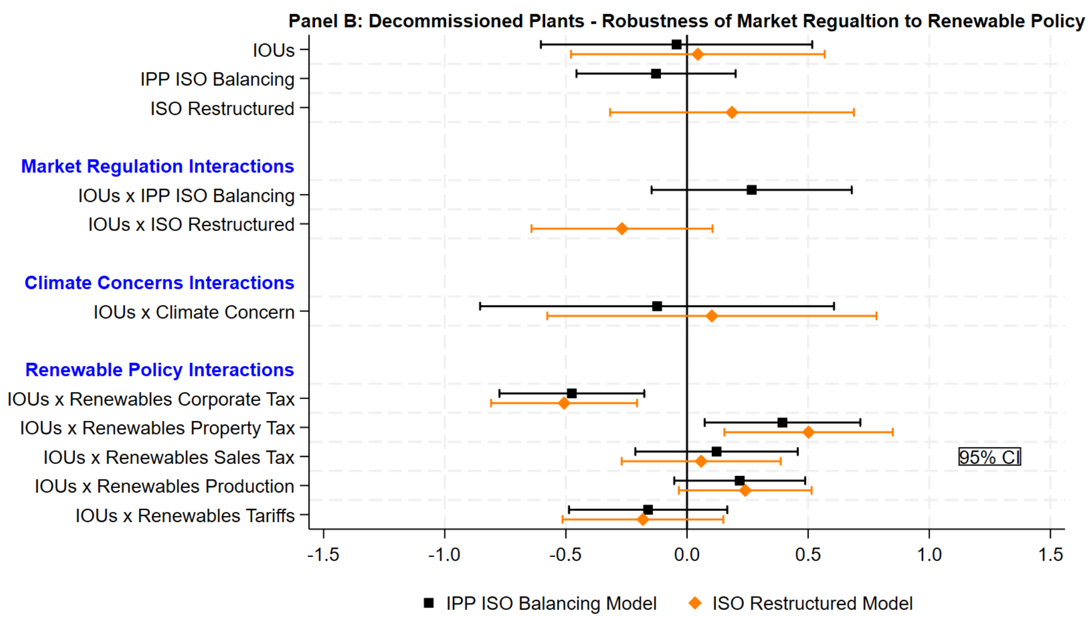


Figure A.4: IOUs Split by Characteristics and Greenfield Plants by Fuel Type

This figure extends the analysis from Figure 6. We analyze greenfield plants by fuel type and split the IOUs into quartiles based on three potential constraints: ESG ratings, credit ratings, and the percentage of coal assets from total capacity.

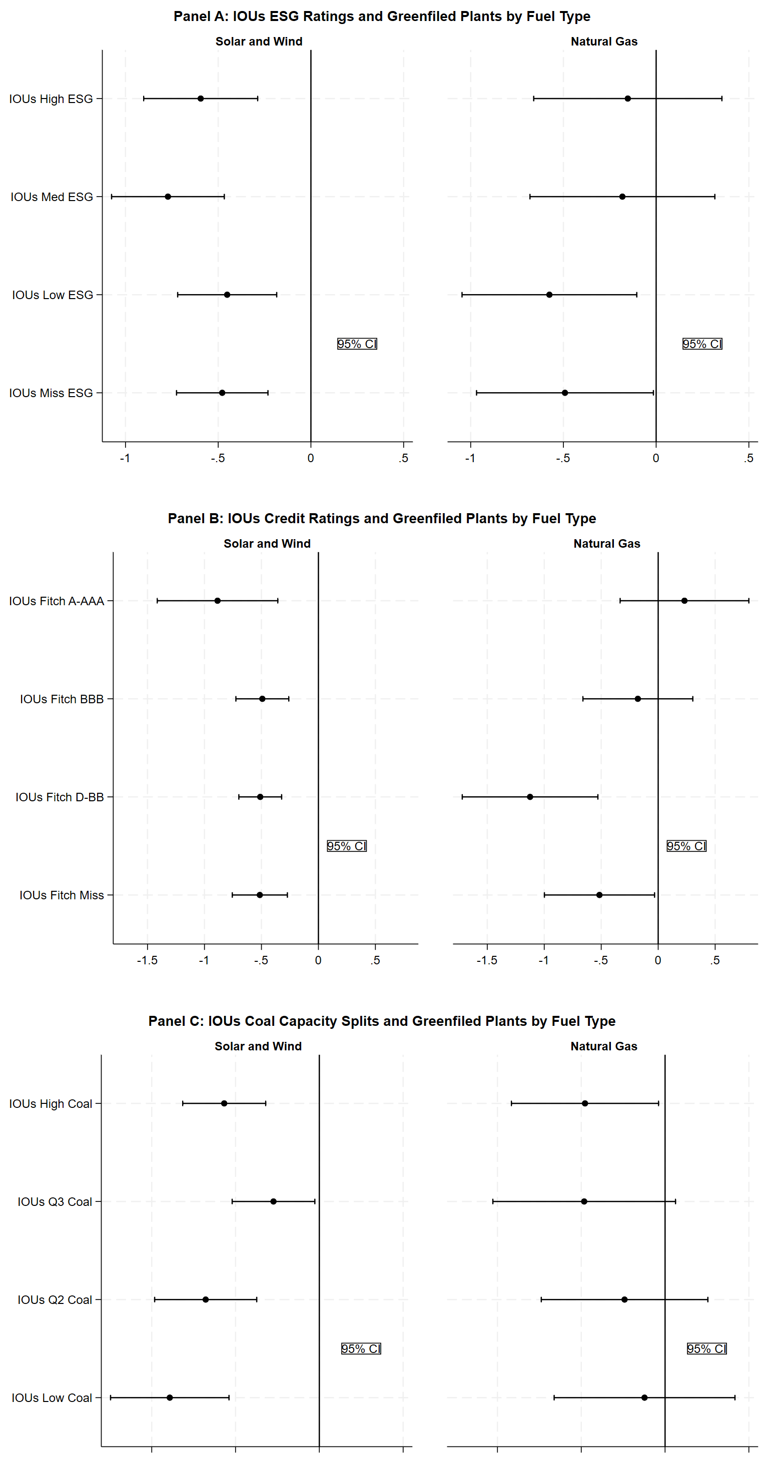


Figure A.5: IOUs Split by Characteristics and Decommissioned Plants

This figure extends the analysis from Figure 6. We analyze power plant decommissioning rates and split the IOUs into quartiles based on three potential constraints: ESG ratings, credit ratings, and the percentage of coal assets from total capacity.

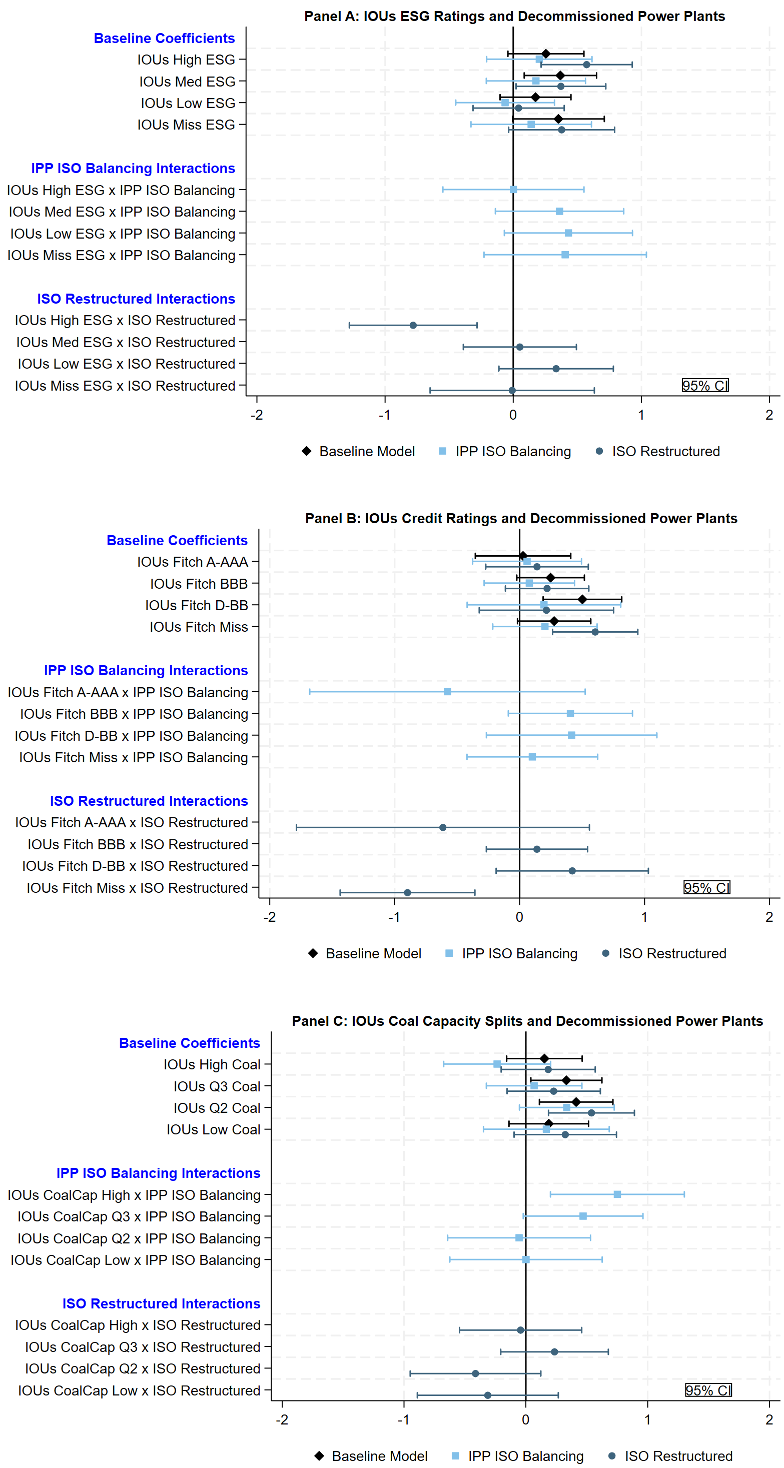


Table A.11: Competing Risks Model: Sales and Decommissioning of Power Plants

Observations are at the plant-prime-mover-month level and the sample includes only power plants with a nameplate capacity of at least 20MW. We present the hazard ratios of a survival analysis using a competing risks model. The sample includes all power plants that have been owned by IOUs at any moment during our sample period. In Columns (1) to (3), the event of interest is a complete sale of a power plant to a new ownership type (not a partial sale or reduced ownership stake), and the competing event is a decommissioning of a plant. In Columns (4) to (6), the event of interest is a complete decommissioning of a power plant (not partial retirement of one generator), and the competing event is a sale of a plant. *IPP ISO Balancing* and *ISO Restructured* are indicators for power plants operating in a deregulated electricity market. In Columns (4) to (6), we present the second stage results of an IV model where we instrument the *ISO Restructured* variable with the difference between the average residential and industrial electricity prices in a state over the 1991–1996 period. We also control either for *Climate Concern* percentile ranking and *Renewables Incentives* aggregate index, or for state fixed effects. *ln Plant Capacity* is the natural logarithm of a plant's monthly capacity. *ln Plant Age* is the natural logarithm of plant age in years. The specifications include fuel-type fixed effects and we present the coefficients for coal, nuclear, hydro, wind, and solar power plants (the omitted category is natural gas plants). We cluster standard errors by plant-prime-mover and report standard errors in brackets. For the IV model, we present the Kleibergen-Paap rk Wald F statistic. *$p < .10$; **$p < .05$; ***$p < .01$.

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Sold Plants (2,767 total plants; 656 events of interest; 377 competing events)						
IPP ISO Balancing	3.189***	2.630***	2.769***			
	[0.342]	[0.302]	[0.296]			
ISO Restructured				2.733***	2.727***	3.151***
				[0.694]	[0.722]	[0.849]
Climate Concern	1.870***	2.211***	1.993***	2.228***	2.566***	2.085***
	[0.321]	[0.374]	[0.332]	[0.479]	[0.510]	[0.433]
Renewables Incentives	0.885***	0.895***	0.899***	0.865***	0.869***	0.873***
	[0.037]	[0.037]	[0.036]	[0.038]	[0.036]	[0.036]
ESG Rating Splits	Yes			Yes		
Credit Rating Splits		Yes			Yes	
Coal Capacity Splits			Yes			Yes
Plant Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Fuel-Type FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	326,312	326,312	326,312	326,312	326,312	326,312
K-P F-Stat				412.852	401.750	402.476
Panel B: Decommissioned Plants (2,767 plants; 377 events; 656 competing events)						
IPP ISO Balancing	0.993	0.935	1.034			
	[0.130]	[0.126]	[0.137]			
ISO Restructured				0.542	0.445*	0.515
				[0.220]	[0.190]	[0.208]
Climate Concern	1.288	1.209	1.140	1.688*	1.586	1.598
	[0.340]	[0.317]	[0.306]	[0.487]	[0.445]	[0.466]
Renewables Incentives	1.068	1.067	1.084	1.069	1.073	1.082
	[0.061]	[0.062]	[0.064]	[0.061]	[0.062]	[0.063]
ESG Rating Splits	Yes			Yes		
Credit Rating Splits		Yes			Yes	
Coal Capacity Splits			Yes			Yes
Plant Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Fuel-Type FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	326,312	326,312	326,312	326,312	326,312	326,312
K-P F-Stat				412.852	401.750	402.476

A.4 Power Plant Operating Performance

We observe that new entrants operate power plants more efficiently than IOUs. Their plants have a lower heat rate and consume less fossil fuel to produce one unit of electricity. This result suggests that the ownership changes are accompanied by operational improvements. Online Appendix Table A.12 examines separately the operating performance of different fuel types. We see that the difference in operating intensity between IOUs and new ownership structures is driven primarily by natural gas power plants, consistent with the interpretation that, in this fuel type, the owners have flexibility as to when to operate a plant, and may face regulatory incentives to increase operating intensity in traditional markets.

Similarly, the differences in operating efficiency between plants owned by IOUs and plants owned by the new entrants are also concentrated among natural gas power plants. We observe that IOU natural gas plants have a 0.86 higher heat rate than natural gas plants owned by the new entrants. The differences in operating efficiency between IOUs and new entrants seem to be relatively larger in deregulated markets but the interactions are only statistically significant under the *IPP ISO Balancing* measure of deregulation.

Table A.12: Operating Performance by Fuel Type

Robustness check of Table 8: We estimate the analysis of operating performance by fuel type.

In this table, observations are at the plant-prime-mover-month level and weighted by nameplate capacity. In Panel A, the dependent variable is the capacity factor, which is the ratio of electricity generation to capacity. We winsorize the capacity factor at 0.5% and 99.5%. In Panel B, the dependent variable is the heat rate, which is the ratio of fuel consumption to electricity generation. We do not observe the heat rate for wind, solar, and hydro power plants. Columns (1) to (3) examine the subsample of natural gas plants, Columns (4) to (6) examine the subsample of coal, waste coal, petroleum coke, and residual petroleum plants, and Columns (7) to (9) examine the subsample of solar and wind power plants. We focus on the ownership by IOUs and also control for the ownership by industry firms, government, cooperatives, and others (the omitted ownership categories are private equity, institutional investors, and foreign corporations). *IPP ISO Balancing* and *ISO Restructured* are indicators for power plants operating in a deregulated market. Columns (3), (6), and (9) present the second stage results of an IV model where we instrument the *ISO Restructured* and *IOUs* × *ISO Restructured* variables with the difference between the average residential and industrial electricity prices in a state over the 1991–1996 period. We control for *ln Plant Capacity*, *ln Plant Age*, *Greenfield 1m*, *Greenfield 12m*, *Decommissioned 1m*, and *Decommissioned 12m*. The specifications include interacted fuel-type, state, and year-month fixed effects. We double cluster standard errors by plant-prime-mover and time, and report standard errors in brackets. $^{*}p < .10$; $^{**}p < .05$; $^{***}p < .01$.

	Natural Gas			**Coal & Petroleum**			**Solar & Wind**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Capacity Factor	Mean Dep. Var. = 0.276			Mean Dep. Var. = 0.481			Mean Dep. Var. = 0.314		
IOUs	0.031**	0.126***	0.063**	-0.025	-0.007	0.050	0.006	-0.000	0.023*
	[0.013]	[0.020]	[0.027]	[0.024]	[0.030]	[0.037]	[0.004]	[0.005]	[0.012]
IPP ISO Balancing		0.137***			-0.023			0.006	
		[0.022]			[0.030]			[0.006]	
IOUs × IPP ISO Balancing		-0.142***			-0.051*			0.011*	
		[0.024]			[0.031]			[0.006]	
ISO Restructured			0.040			0.041			-0.020
			[0.039]			[0.047]			[0.013]
IOUs × ISO Restructured			-0.136**			-0.085			-0.033
			[0.053]			[0.055]			[0.037]
Plant Age and Capacity Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Owners	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fuel-State-Year-Month FE	Yes	Yes		Yes	Yes		Yes	Yes	
Fuel-Year-Month FE			Yes			Yes			Yes
Observations	463,576	463,576	480,665	100,407	100,407	140,237	322,113	322,113	323,749
Adjusted R-squared	0.378	0.386		0.610	0.613		0.672	0.673	
Panel B: Heat Rate	Mean Dep. Var. = 11.816			Mean Dep. Var. = 10.913					
IOUs	0.857***	0.255	0.827**	-0.130	-0.220	-0.835***			
	[0.161]	[0.208]	[0.353]	[0.174]	[0.242]	[0.300]			
IPP ISO Balancing		-0.862***			0.186				
		[0.272]			[0.282]				
IOUs × IPP ISO Balancing		0.855***			0.325				
		[0.302]			[0.278]				
ISO Restructured			-0.296			-0.981**			
			[0.524]			[0.458]			
IOUs × ISO Restructured			0.275			1.109**			
			[0.710]			[0.482]			
Plant Age and Capacity Controls	Yes	Yes	Yes	Yes	Yes	Yes			
Other Owners	Yes	Yes	Yes	Yes	Yes	Yes			
Fuel-State-Year-Month FE	Yes	Yes		Yes	Yes				
Fuel-Year-Month FE			Yes			Yes			
Observations	322,377	322,377	340,029	86,581	86,581	122,811			
Adjusted R-squared	0.273	0.275		0.349	0.351				