Brown Capital (Re)Allocation*

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Abstract

We study who owns coal power plants – the largest single source of carbon emissions – in Europe. A sharp increase in private firms' ownership was met by a large decline in public equity ownership. This decline was not driven by public equity investors selling plants, but by their scaling down of plants quickly. State investors played a crucial role, selling to private firms and slowly scaling down their plants. We calibrate a model in which asset owners vary in how they value externalities. Nationalization by state investors that value social factors (jobs, "energy security") can hinder "green finance" in decreasing emissions.

Keywords: Energy transition, capital reallocation, exit vs. voice, state ownership, climate finance, energy security, private equity
JEL codes: G32, G11, E440, H54, Q40

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1 Introduction

A "green transition" is sure to have dramatic effects on capital allocation across the globe. Any significant reduction in greenhouse gas emissions would imply a large-scale transformation of many key sectors of the economy. In particular, it not only calls for scaling up "green", low-carbon, capital but crucially also scaling down "brown," carbon-intensive capital as well [Hartzmark and Shue, 2023, Green and Vallee, 2022]. An absolutely central sector is power production, in which traditional fossil fuels are progressively being challenged by renewable energy sources. In particular, phasing out coal power plants is seen as an absolute priority in any scenario projecting a reduction in brown capital and emissions, given that burning coal is by far the most carbon-intensive way to produce energy. That makes coal the single largest source of carbon emissions globally[1] and the United Nations Secretary General has dubbed a coal phase-out the "single most important step" in addressing climate change.[2] In Western economies, recent years have witnessed the multiplication of announcements of government commitments to end coal and the rise of competition from renewables. Coal has also become a major red flag in the rising "green finance" movement.

In spite of this declining trend, there are nevertheless still plenty of active coal plants in Western economies. This paper asks: Who then owns this (very) brown capital? This is important since owners (i.e. equity investors) have the largest say in how plants are run.[3] There is widespread concern that climate-conscious investors might stop at selling brown capital, instead of scaling it down, i.e. choosing "exit" over "voice." The concern is that simply reallocating brown capital across investors might lead to a limited reduction in aggregate carbon emissions. In addition to comparing publicly-listed firms and private investors [Duchin et al., 2022, Andonov and Rauh, 2022], we also investigate the role of states as investors, who are thought to potentially care directly about externalities while often being significant

[1] Source: "It's critical to tackle coal emissions," *International Energy Agency* , October 8, 2021, Link.

[2] Source: "Statement by the Secretary-General on the announcements by the United States and China on climate action," *United Nations*, September 21, 2021, Link

[3] They are also the most exposed to long-run risk in asset valuation (i.e. "stranded assets").

shareholders in the energy sector.

In the first part of the paper, we unpack the dynamics of coal ownership by merging asset-level data on firms' plant ownership (real capital) with firms' shareholder data (financial capital) for the universe of coal power plants in the European Union since 2015. The asset-level data include the amount of carbon emissions produced by each plant, which we use to measure the scale of firms' coal power plants. We use these data to create a bottom-up measure of ownership of carbon emissions from coal-fired power production and document changes in ownership shares across three investor groups: public equity investors, private investors, and state investors. In spite of a sharp increase in the private ownership of coal emissions, we introduce a formal decomposition to show that the large decline in the public equity share was not due to *capital reallocation* ("exit") but to *capital utilization*: these investors scaled down plants, not sold them. Instead, state investors played a crucial role: they sold to private firms, while being the slowest at scaling down their plants. In the second part of the paper, we illustrate the economics of brown capital reallocation by calibrating a model that incorporates production externalities. Investors (private, public, states) differ in how they value externalities, and trade is subject to financial frictions. We argue that the possibility of nationalization of brown assets by state investors that value social factors (e.g. jobs, "energy security") is an important limit to the ability of "green finance" to decrease aggregate emissions, in line with recent episodes in Germany and Poland.

We focus on European coal power plants for two reasons. First, Europe is a large historical coal power producer but also at the forefront of the green transition, at least since the Paris Agreement in 2015. The European Union has witnessed the most ambitious commitments to emission reduction targets across both governments and the private sector, with many explicit references to a coal phase-out. This region experienced the largest decline in coal power capacity since 2015, of about 25%. Second, there is a wide range of firm ownership patterns in Europe and all main types of investors play an important role, including publicly listed firms, private firms, and states and local governments. The reallocation dynamics at play in Europe are thus particularly informative.[4]

We build a bottom-up measure of ownership of coal emissions by combining two levels of micro-data. We first gather data on which firms own plants using an asset-level database constructed by Beyond Fossil Fuels. For the period 2015-2022 and for all European coal power plants, we observe its location, generation capacity, and crucially the name of the firm(s) owning it. We also observe a measure of scale via plant-level verified CO2 emissions that come from the European carbon market (the ETS). We merge this plant-level data with firm-level shareholder data. For publicly traded firms, we use detailed data on equity investors from S&P Capital IQ. For other firms, which are either state-owned or private, we manually collect shareholder information from annual reports and other sources. We classify investors as belonging to one of three investor groups: (i) public equity investors (investing in listed firms), (ii) private investors (unlisted firms), and (iii) state investors (investing in both listed and unlisted firms). Some of our analysis will nevertheless be more granular and we will study heterogeneity within these groups. We create a panel of investor groups' ownership share of coal emissions by taking for each year the product of each plant's emissions and the investor's equity share in the firm owning that plant, summed across all plants, and divided by total coal emissions.

We first document aggregate ownership dynamics. There is a large rise in private ownership of 12 percentage points, doubling its share during our sample period. This rise is the sum of a large decline in the share of public equity investors of 9 percentage points and a smaller decline of state ownership of 3 percentage points. The aggregate trends however mask the origin of these dynamics.

To this end, we introduce a formal decomposition of ownership changes that distinguishes between *capital reallocation* and *capital utilization*. Indeed, an investor can reduce its coal emissions ownership by selling assets (reallocation), or by scaling down its plants (utilization),

[4]In a global context, North America is the only other region with declining coal capacity. The ownership patterns in Europe also contrast with China and other emerging economies, as well as with the U.S., which are dominated by state-owned enterprises and publicly listed firms, respectively.

or both. This empirical decomposition aims to isolate to the idea of "exit" (divestment) that is traditionally opposed to "voice" (action, engagement, etc.).[5] This is one of the great advantage of our asset-level data: isolating exit is generally difficult with firm-level asset holdings data only.

This decomposition reveals that aggregate trends mask striking patterns. Perhaps surprisingly, the decline in the public equity share was entirely driven by a quick decline in utilization, not reallocation. In other words, these investors have been closing or scaling down plants faster than other investors, and not selling to them. There is thus little evidence of "exit" (asset sales) of public equity investors in coal. Instead, the decomposition makes it clear that state investors played a crucial role: they were the ones that sold to private firms and were also the slowest in scaling down their plants. In that sense, states (as investors) seemed to have slowed down the transition.[6] For robustness, we confirm that these findings are not purely driven by composition effects across investors, due to, for instance, differences in technological obsolescence (age) or location (country) of their initial capital. Looking at levels of emissions rather than shares also does not change the picture. While all investors have reduced capital utilization, public equity investors have reduced it relatively more,[7] and we see a large reallocation of emissions from state investors to private investors.

Moreover, we find striking differences within states investors when we distinguish between national, local, and foreign states. Over our sample period, foreign and local states have massively decreased their ownership share by 13 percentage points, from 27% to 14%, while national states have increased their ownership share by 9 percentage points, from 19% to 28%. Our decomposition reveals what led to these diverging paths. Foreign and local state

[5]The decomposition is exact once we account for a covariance term, which is typically small.

[6]We can also use our data to formally quantify the relative contribution of real reallocation versus financial reallocation to capital reallocation, i.e. how much of investors' sale of assets is from trading plants vs. trading shares. There were diverging patterns of real versus financial reallocation across investors. Private firms bought plants from states, while until 2022 public equity investors bought shares from states. We discuss the 2022 reversal in more detail below in the context of (re)nationalizing brown assets.

[7]More precisely, in aggregate, emissions have been declining since 2015 in spite of a recent rebound in 2021. Public equity investors reduced capital utilization relatively more between 2015 and 2020. They also increased utilization relatively less after 2021. We discuss these dynamics in more detail in the main text.

investors decreased their ownership purely via reallocation: they sold plants to private firms. The massive sale of German plants owned by Swedish utility Vattenfall to private firm EPH was the most prominent example. National state investors in contrast were the slowest to scale down their existing plants, implying a large rise in their ownership share.

To understand the economics of brown capital reallocation, we present a model that differs from traditional models of capital reallocation in one key aspect: the presence of externalities in production, which will generate new insights. Capital owners differ in how they value externalities, which implies dispersion in asset valuation and incentives to trade. We introduce two important ingredients related to finance and governance. First, there are financial frictions in the acquisition of new capital. Second, we take the structure of socially responsible "investment mandates" seriously [Oehmke and Opp, 2024]. Beyond caring about climate externalities, it crucially matters *how* investors care. Investors with "narrow" mandates only internalize externalities of the capital they currently hold (a micro perspective). On the other hand, investors with broader mandates internalize the effects of their capital allocation on aggregate emissions (a macro perspective). Narrow mandates give strong incentives to choose "exit" and sell plants instead of scaling them down.

We calibrate the model using our micro-data and moments from our formal decomposition. We find reasonable values for model parameters that can rationalize the key facts in ownership dynamics documented above. There has been a large aggregate decline in profitability of coal since 2015. The valuation of climate externalities is large relative to profitability, and financial constraints are binding. Public equity investors have relatively broad mandates, explaining why they preferred to scale down rather than sell to private firms. States seem to have a much higher valuation of brown capital, consistent with the existence of social factors, such as jobs or stable electricity supply ("energy security") that other investors might not value as highly. Our data suggests that these potential social factors are large relative to climate externalities.[8] That can explain why state investors scaled down less than public equity investors. National

[8]Note however that we do not want to imply that states always behave as benevolent social planners.

states have a broader mandate than foreign and local states. That can explain why foreign and local states sold more to private firms and scaled down less than other investors.

We use the calibrated model to illustrate some of the key economic implications of brown capital reallocation. In particular, we focus on the effects of the rise of "green finance," understood broadly as the increased attention paid by financial institutions to the carbon content of their capital allocation. We argue that, while "green finance" can decrease aggregate emissions, the existence of states as investors is an important limit.

Through the lens of the model, the first effect of a more climate-conscious financial sector is to tighten financial constraints for potential buyers of polluting plants. Interestingly, unlike in traditional models driven by productivity dispersion, trade is not necessarily (socially) efficient if driven by externalities. Retiring units instead of selling them is necessary to decrease aggregate emissions. In that sense, impediments to trade, such as financial frictions, might improve capital allocation, instead of reducing it. This has the flavor of theories of the second-best. Moreover, a second effect is a larger share of investors with broad mandates. Both effects reduce aggregate emissions and are quantitatively important. In the counterfactual in which there are no financial frictions and public equity investors have mandates as narrow as foreign states, the decline in aggregate emissions is 12pp lower, with both forces contributing rouhgly equally.

Importantly, we argue that "green finance" not only affects firms' decisions, but also the state's incentives to intervene. While "green finance" can help correct climate externalities and substitute for government intervention to retire plants, we point out that it might also increase incentives to intervene because of social factors. When the state values social factors such as jobs and "energy security" relatively more than other investors, that introduces the possibility of nationalization: the state might want to purchases a unit that another owner plans to retire. Through the lens of our model, the incentives to nationalize are the largest when: (i) the value of social factors are large relative to pecuniary profits; as well as (ii) financial frictions are tight; and (iii) firms' mandate are broad, such that firms' incentives to scale down are large.

In our calibration, we find that these effects are substantial. Almost 50% of units retired by public equity investors are potential targets for nationalization (representing 27% of initial emissions). However, incentives to intervene are significantly smaller in the counterfactual with no financial frictions and narrow mandates.

The state has incentives to undo some of the effects of climate-conscious investors if it believes these investors do not sufficiently value some social factors. This is consistent with recent episodes of nationalization in Germany and Poland, two country heavily reliant on coal in their energy mix. In 2022 and 2023, these governments have respectively spent $8 billion and $4 billion of taxpayer money on brown assets by purchasing coal plants from publicly listed firms.[9] At a macroeconomic level, it is thus important to understand how economic and policy shocks to brown capital affect not only the private sector, but also incentives for states to intervene in this way.

Related Literature: This paper contributes to several strands of an emerging literature studying how the green transition affects the real economy and capital markets.

First, our empirical analysis sheds light on some new key insights from the theory of socially responsible capital. Broccardo et al. [2022] argue that "exit" (divestment and boycott) can often lead to worse outcomes than "voice" (action, engagement) investment strategies in a world where companies generate externalities (see also Berk and Van Binsbergen [2021]). We also take the structure of socially responsible investment seriously: Oehmke and Opp [2024] and Green and Roth [2021] show that socially responsible investors that only consider externalities in their own portfolio allocate their capital inefficiently from the perspective of generating impact. Hartzmark and Shue [2023] provide evidence that directing capital away from brown firms and toward green firms may be counterproductive, while Kahn et al. [2023] find that engagement by shareholders can be more effective to reduce carbon emissions by firms than divestment.

[9]Sources: "German Government Nationalizes Uniper in Move to Secure Energy Supply", New York Times, September 22, 2022; Link; "Poland's PGE, Enea, Tauron, Energa get state offers for coal assets", Reuters, July 15, 2023; Link.

Distinguishing between reallocation ("exit") and utilization is difficult with firm-level data alone.[10] In that way, we complement recent work that also uses asset-level data by Duchin et al. [2022] and Andonov and Rauh [2022]. Asset-level data allows us to study the widespread concern that publicly traded firms might respond to environmental pressure by only selling assets. In contrast to Duchin et al. [2022] that studies the asset market for pollutive plants, we find that this is generally not the case for coal plants, in line with Andonov and Rauh [2022]'s study of fossil-fuel power plants in the U.S. This is possibly due to coal investment being explicitly "enemy number 1" for many stakeholders and as such particularly scrutinized. While the goal of this paper is not to explicitly explain the origins of environmental pressure, we relate more generally to works studying how the rise of "green finance" has affected different investors and stakeholders. Within the coal sector, Green and Vallee [2022] and Sastry et al. [2023] study for example the role of bank lenders.[11]

Second, we uncover a key role of states as investors in fossil fuels. Indeed, another advantage of asset-level data is that it is not restricted to particular firms (say listed firms) or investors (say mutual funds investing in equities). This contrasts with a common focus in prior work on private vs. public firms, often using U.S. data [Shive and Forster, 2020, Chen and Wittry, 2024]. In the data, we find that state ownership is large and has been rising in recent years, in part due to a wave of re-nationalization of coal power plants observed in Germany and Poland. Given that we often associate states with emissions targets, renewable energy subsidies or carbon markets, is there a "paradox" of state ownership? We argue that it is crucial to understand the role of (short-run, local) social considerations, such as jobs and energy security, that states often balance with (long-run, global) climate externalities. Baranek et al. [2021] present particularly provoking evidence that state-owned energy firms in Italy do not internalize carbon pricing in their production decisions. While growth in re-

[10] Berg et al. [2023] is an important exception, although their data is restricted to publicly-listed firms and presents challenges in identifying who stands on the receiving end of asset sales.

[11] Briere et al. [2023] and Brière et al. [2018] study how large institutional investors vote on shareholder resolutions aimed at mitigating climate externalities. There is also many works investigating how ESG concerns have affected public equity markets [Koijen et al., 2020, Baker et al., 2022, Giglio et al., 2023, Van der Beck, 2021] and bank lending [Kacperczyk and Peydró, 2022, Ivanov et al., 2023, Giannetti et al., 2023].

newable power infrastructure can generate substantial welfare gains [Arkolakis and Walsh, 2023, Adrian et al., 2022], it is capital intensive and takes significant time to build. Blonz et al. [2023], Du and Karolyi [2023], and Brey and Rueda [2024] document how the energy transition away from fossil fuels caused broad-based negative impacts on communities historically built around these industries. There is a potential link with arguments that "E" is being over-weighted relative to "S" within the ESG framework [Saul, 2022]. In a global context, countries that are expanding coal capacity, like China and emerging markets, tend to have many state-owned enterprises. Insights gleaned from our European evidence might thus be relevant more generally.

Third, we reveal new insights by incorporating production externalities in classical models of capital reallocation, surveyed in Eisfeldt and Shi [2018]. This allows us to study equilibrium interactions between profit-maximizing, socially responsible investors, and state investors. We also highlight how financial frictions can reduce aggregate emissions and complement Lanteri and Rampini [2023] that focuses on the adoption of clean technology in the presence of financial constraints.

2 Background and Data

2.1 Coal and the Green Transition

Coal combustion is currently the most carbon-intensive way to produce power. Even compared to other fossil fuels, coal power plants produce significantly more greenhouse gas emissions per unit of output. The International Energy Agency estimates that coal is the single largest source of emissions globally, responsible for as much as a fifth of the total.[12] For example, in the European Union, all top ten largest emitters in 2022 were coal power plants.[13]

For this reason, coal has been at the center of the "green transition," i.e. efforts to reduce

[12]Source: "It's critical to tackle coal emissions," *International Energy Agency*, October 8, 2021, Link.

[13]Source: "Repeat offenders: coal power plants top the EU emitters list," *Ember Climate*, May 23, 2023, Link.

carbon emissions by transforming key sectors of the economy. Phasing out coal power plants is seen as a priority in any scenario projecting a reduction in aggregate emissions. The United Nations Secretary General has dubbed a coal phase-out the "single most important step" in addressing climate change.[14] In Western economics, recent years have also witnessed the multiplication of announcements of government commitments to end coal, in conjunction with increased subsidies for competing renewable energy sources. Coal has also become a major red flag in the rising "green finance" movement after the 2015 Paris Agreement, playing a key role in ESG ratings for instance. As such, many private sector firms made explicit commitments against coal.

In spite of this declining trend, there are nevertheless still many active coal plants in Western economies. This paper investigates who are the ultimate owners of these brown assets (i.e. equity investors) since they have the most say in how plants are run.[15] They are also the most exposed to long-run risk in asset valuation ("stranded assets"). A widespread concern is that some investors might choose to sell brown capital to other investors, instead of scaling it down. This would only lead to reallocating brown capital across investors and would achieve a limited reduction in aggregate carbon emissions.[16] Note that the goal of this paper is not to isolate a specific source of environmental pressure, but to understand the market dynamics for brown capital. There are many factors contributing to a declining trend in coal, and the extreme illiquidity of assets such as power plants implies that ownership changes often take years to realize.

We mainly focus on European coal power plants for three reasons.[17] First, Europe is a large historical coal power producer. Second, the European Union is however also at the forefront of the green transition, at least since the Paris Agreement in 2015. The EU has

[14] Source: "Statement by the Secretary-General on the announcements by the United States and China on climate action," *United Nations*, September 21, 2021, Link.

[15] Shareholders may engage with firm decision-making through shareholder voting, and also through private communication [Dimson et al., 2015, Azar et al., 2021, Kahn et al., 2023].

[16] More generally, this relates to concerns over "greenwashing", i.e. when words are not followed by the appropriate actions.

[17] Section IA.1 provides some results for the United States.

witnessed the most ambitious commitments to emission reduction targets. As a group, the EU announced the "Green Deal" in 2019, followed by the "Fit for 55" initiative which aims to significantly reduce emissions by 2030. All EU governments have an explicit timeline for a coal phase-out. While in 2016, the EU was the fourth largest region in terms of coal capacity, it was the region that experienced the largest decline in coal capacity since then, at about -25%. North America was the only other region that experienced a decline.[18] Third, there is a wide range of firm ownership patterns in Europe and all main types of investors play an important role. For comparison, the US is dominated by publicly traded companies with virtually no state ownership, while China is dominated by state-owned enterprises. In contrast, large coal power producers in the EU include a mix of publicly traded firms with low and high state ownership shares, as well as multiple private firms backed by private equity investors and wealthy individuals.[19]

2.2 Data

2.2.1 Coal Power Plants

The primary dataset on coal power plants used in this paper is the coal plant database from Beyond Fossil Fuels ("BFF data"), which tracks coal power plants in the EU (including UK) from 2015-2022. While the Global Energy Monitor also tracks coal plants in the EU, the BFF data provides greater quality detail on plant ownership and data on actual CO2 emissions for plants in the EU. The BFF data contain information such as the location, generation capacity, operational status, announced retirement year, owner names, and realized CO2 emissions for each coal plant. Coal plants may contain one or more coal units that contribute to the

[18]The top 4 coal power producers in 2016 were: China 50%, US and Canada: 15%, India: 10%, EU and UK: 8.2%. Figure IA.4 in the Internet Appendix shows the decline across regions since 2016. Source: Global Energy Monitor.

[19]Table IA.1 in the Internet Appendix shows the average share of state investors' ownership for the ten largest coal power producers in four regions: the United States, the EU, China, and India. While the US has a low average state investor share (10%), it is much higher in China (80%). Interestingly, Europe sits in the middle with about 30%. Table IA.2 in the Internet Appendix also shows that Europe has a much more varied ownership structure relative to the United States or China. India has a comparable mix of ownership structure to the EU. Source: Global Energy Monitor.

generation capacity of the plant. In total, the database tracks 356 plants and contains 2,837 plant-year observations. A total of 136 firms who have ownership stakes in coal plants are represented in the data. The NGO Beyond Fossil Fuels researches each individual data point, collecting information from a wide variety of sources, including but not limited to government publications and news articles. In the BFF data, the plant generation capacity represents the amount of electricity the plant can produce at maximum power, while the CO2 emissions produced by the plant provides a measure of the actual utilization of the plant. The CO2 emissions reported in the BFF data are annual realized CO2 emissions for each coal plant, which are sourced from the European Union Emissions Trading System (EU ETS).[20] CO2 emissions data from the EU ETS are subject to monitoring and verification.[21]

2.2.2 Firm-Level Shareholder Data

For firms that are publicly-traded, we collect detailed data from S&P Capital IQ on their equity investors, from 2015-2022.[22] The investor data from Capital IQ include the shareholder's name, percentage of total shares outstanding owned, and shareholder type. The shareholder type distinguishes whether the shareholder is a state investor or (non-state) institutional investor.[23] State investors may be state or local governments, or entities owned by state or

[20]In the BFF data, values for CO2 emissions for the most recent year of 2022 are incomplete. We use EU power plant emissions data from EMBER to supplement the CO2 emissions data in 2022. EMBER data is also derived from the EU ETS.

[21]Source: "Monitoring, reporting and verification of EU ETS emissions," *European Union Directorate-General for Climate Action*; Link

[22]We will make two comments here. First, some publicly traded firms may have other firms as a large shareholder. For example, E.ON owned 46.65 % of Uniper in 2017. When this occurs, we treat the shareholders of the investing firm as shareholders of the focal firm. The shareholder percentage is determined by multiplying the proportion of shares held by the investing firm in the focal firm with the proportion of shares held by the shareholder in the investing firm. Second, if a firm is acquired, the BFF data continues to associate the target firm with its pre-acquisition plants. For example, the Polish state-controlled power company PGNiG was acquired by another Polish power company Orlen before the end of 2022; the two coal plants originally owned by PGNiG continue to be recorded as owned by PGNiG at the end of 2022. Post-acquisition, we assign the shareholder structure of the acquiring company (Orlen in this example) to the target company (PGNiG). Thus, we treat acquisitions are events of financial reallocation (trading shares), rather than real reallocation (trading plants across firms).

[23]There is a small percentage of investors who are classified as "individual/insiders" or whose type is unclassified by Capital IQ. For large unclassified investors, we manually assign them to be a state or institutional investor. The remaining unclassified shareholders and individual/insiders, who together own $< 0.1\%$ of annual aggregate CO2 emissions, are collectively categorized into the institutional investors category.

local governments. For firms that are not publicly traded, we manually collect information on the percentage of shares that are privately held or state-owned using sources such as annual reports or press releases. This process allows us to classify investors for each firm at calendar year-end from 2015-2022 into three investor groups: (i) public equity investors, (ii) private equity, and (iii) state investors. Public equity investors include retail or institutional investors in publicly traded firms. State investors include state-owned shares in both publicly traded firms and non-publicly traded firms.

The coal power plant data gives us each firm's percentage ownership in each plant (real-side), and the firm-level shareholder data gives us the percentage ownership of each investor category in each firm (financial-side). Combining the two datasets provides us with a bottom-up measure of percentage ownership of each investor category in coal plants. It allows us to determine the percentage of CO2 emissions and coal capacity associated to and owned by each investor category, based on their ownership in these coal plants.[24]

2.3 Coal in Europe

To motivate the main analysis, we present a few stylized facts about coal in Europe through the lens of our micro-data. Figure 1 illustrates the decline in aggregate coal power capacity driven by many power plant closures during our sample period.[25] Emissions have also fallen over time, with two notable differences. First, the decline since 2015 is proportionally larger for emissions relative to capacity (50% vs. 25%). This reveals a mix of permanent closures (a decline in generation capacity) and temporary scaling down (a decline in the emission rate per unit of open capacity).[26] Second, we saw a small rebound in aggregate emissions in 2021-2022 after years of continuous decline. We discuss these effects in more detail below.

[24]Select consolidated versions of the data used in this study are made available online [Link].

[25]Figure IA.5 in the Internet Appendix shows that the ownership of coal capacity changed very little in European countries outside of the EU. Power producers are all either private or state-owned, with virtually no change in coal ownership share between these groups.

[26]Note that unlike in the United States, conversion of coal plants to natural gas was extremely rare in Europe during our sample period. Some major conversions have recently been announced, but yet to be realized, for example in Poland (Link).

Figure IA.6 and IA.7 in the Internet Appendix break down emissions in 2021 across countries and firms, respectively. Plants in Germany and Poland represent almost 75% of all EU coal emissions, followed by the Czech Republic. As a motivation for looking at ownership dynamics across investor groups, it is interesting to look at the three largest firms: PGE (Polish), RWE (German), and EPH (Czech). Figure 2 shows that they have very different ownership structures. PGE is a publicly traded company but is 61% owned by the Polish state. In contrast, RWE is publicly traded but is only 10% owned by state investors. EPH differs from both, being 100% private.[27] Figure IA.8 in the Internet Appendix also shows that these three firms experienced very different trajectories in their carbon emissions over our sample period: RWE has reduced its emissions significantly more than PGE, while EPH's emissions have increased in contrast.

3 Coal Emissions Ownership Dynamics

3.1 Aggregate Dynamics: 2015-2022

We start by documenting aggregate dynamics across three main categories. We classify each investor as belonging to one of three investor groups: (i) public equity investors (investing in listed firms), (ii) private investors (unlisted firms), and (iii) state investors (investing in both listed and unlisted firms). Later tests use more granular investor categories and study heterogeneity within the three main groups. For investor group g, define their coal emissions ownership share across all plants i:

$$\text{Ownership share}_t^g = \frac{\text{aggregate group-owned emissions}_t}{\text{aggregate emissions}_t} = \sum_i \omega_{i,t}^g \frac{e_{i,t}}{E_t} \tag{1}$$

In this formula, $e_{i,t}$ is the emissions of plant i at date t, which is a measure of scale of operations, with aggregate emissions being $E_t = \sum_i e_{i,t}$. $\omega_{i,t}^g$ is investor g's ownership share of

[27] EPH is almost entirely owned by Czech billionaire Daniel Kretiznky.

plant i at date t, which is the product of the firm share of the plant times the investor share of the firm.

Figure 3 illustrates aggregate emissions ownership dynamics. Three key facts emerge. First, there is a large rise in private equity ownership of 12 percentage points, more than doubling its share during our sample period from 9% to 21%. Mechanically, this rise must be matched with a decline in other investor groups' ownership shares. The second fact is there is a large decline in the share of public equity investors of 9 percentage points, from 45% to 36%. Third, the state ownership share is large and more stable: it hovers around 40%-45% throughout the sample, with a small overall decline of 3 percentage point.[28][29]

The aggregate trends however mask the origin of these dynamics. For instance, did public equity investors sell to private firms or did they scale down their plants faster than other investors? To answer this question, we next introduce a decomposition that will be at the heart of our empirical analysis.

3.2 Decomposition: Capital Reallocation vs. Capital Utilization

We introduce a formal decomposition of ownership changes that distinguishes between *capital reallocation* and *capital utilization*. Indeed, an investor can reduce its coal ownership by selling assets, or by scaling down its plants, or both. There is an analogy between the first capital reallocation term of this empirical decomposition and the conceptual notion of "exit," in which investors choose to divest, i.e. selling brown assets to another party. This is often contrasted with investors using their "voice" and choosing to engage and take actions to change firm behavior, i.e. scaling down existing plants. The second capital utilization term captures the ultimate change in firm behavior, but not the means by which it was achieved.

Formally, the emissions ownership share of investor group g can change between t_0 and t

[28]We discuss the recent rebound in state ownership in Section 4.

[29]Note that in Europe state ownership is restricted to "strategic" sectors such as energy, infrastructure, and defense. For instance, in France the state owns approximately the same amount of shares of the main CAC40 stock market index as BlackRock, but only in a dozen firms.

because ω_i^g (plant ownership) changes and/or e_i (plant scale) changes:

$$\Delta_{t_0 \to t}\text{Ownership share} = \sum_i \omega_{i,t}^g \frac{e_{i,t}}{E_t} - \omega_{i,t_0}^g \frac{e_{i,t_0}}{E_{t_0}} \tag{2}$$

$$= \sum_i (\omega_{i,t}^g - \omega_{i,t_0}^g) \frac{e_{i,t_0}}{E_{t_0}} + \sum_i \omega_{i,t_0}^g \left(\frac{e_{i,t}}{E_t} - \frac{e_{i,t_0}}{E_{t_0}}\right) + \sum_i (\omega_{i,t}^g - \omega_{i,t_0}^g)\left(\frac{e_{i,t}}{E_t} - \frac{e_{i,t_0}}{E_{t_0}}\right)$$

This is an exact decomposition of change in ownership share that includes three terms:[30]

1. **Capital reallocation** $\sum_i (\omega_{i,t}^g - \omega_{i,t_0}^g) \frac{e_{i,t_0}}{E_{t_0}}$**:** Keeping plant scale constant, how much did changes in plant ownership contribute to the change in ownership share?

2. **Capital utilization** $\sum_i \omega_{i,t_0}^g (\frac{e_{i,t}}{E_t} - \frac{e_{i,t_0}}{E_{t_0}})$**:** Keeping plant ownership constant, how much did changes in plant scale (emissions) contribute to change in ownership share?

3. **Covariance term** $\sum_i (\omega_{i,t}^g - \omega_{i,t_0}^g)(\frac{e_{i,t}}{E_t} - \frac{e_{i,t_0}}{E_{t_0}})$**:** The effect of changing ownership exactly at plants that changed scale. This is often the smallest term empirically.

This decomposition reveals that aggregate trends mask striking patterns, as illustrated in Figure 4. Perhaps surprisingly, the left panel shows that the decline in public equity investors' ownership was entirely driven by a quick decline in utilization, not reallocation, i.e. the capital reallocation term is not negative. In other words, these investors have been closing or scaling down plants faster than other investors, and not selling to them. There is thus little evidence of "exit" (asset sales) of public equity investors in coal. (We discuss in detail the 2022 drop in public ownership share in a later section – we will see it differs from traditional "exit").

This evidence sheds light on the widespread concern that firms, especially listed corporations, might respond to environmental pressure by only selling assets. We find that, in the case of coal, this is generally not the case: public equity investors are the group of coal owners that most aggressively scaled down since the Paris Agreement. This contrasts with the evidence on pollutive manufacturing plants in Duchin et al. [2022]. This is possibly due to the

[30] The decomposition requires a balanced panel of units. For units that closed before the end of our sample, we set their owners at the time of closure to be their owners in subsequent periods and set their emissions to zero. For units that were created after the beginning of our sample, we set their owners at the time of creation to be their owners in prior periods and set their emissions to zero.

nature of coal being explicitly "enemy number 1" for many stakeholders and as such particularly scrutinized. Indeed, many NGOs publish lists of institutions active in coal, such as the "Global Coal Exit List" regularly updated by Urgewald and its forty partner organizations. Our evidence is consistent with the case of fossil fuel plants in the United States [Andonov and Rauh, 2022].

Instead, the decomposition makes it clear that state investors played a crucial role in the rise of private ownership. The right panel first shows that they have a very large negative reallocation term, indicating that they sold coal assets during this time. This is comparable to the very large positive reallocation term for private firms in the center panel. This implies that state investors were the ones that sold to private firms and choosing to "exit." The right panel also shows a very large positive capital utilization term, which means that state investors have been the slowest group to scale down their plants. Both of the facts suggest that states (as investors) have contributed to slowing down the transition away from brown capital.

This figure also makes clear how much aggregate dynamics masks the underlying patterns. In particular, we can estimate how ownership dynamics would have evolved in the absence of asset sales to other investors, i.e. without brown capital reallocation. This corresponds to the red lines of capital utilization. The private equity share would have increased by only 1pp instead of doubling. The share of public equity investors would have still fallen by 7pp but at the expense of an almost equal *rise* in state investor share, entirely driven by a failure of states to scale down plants as fast as public equity investors. Note also that looking at emissions levels instead of shares does not change the picture.[31][32]

[31] In aggregate, emissions have been declining since 2015 in spite of a recent rebound in 2021, as shown Figure IA.9 in the Internet Appendix. Figure IA.10 shows that applying the decomposition to the level of emissions of each investor groups leads to similar results. We see a large transfer of emissions from state investors to private investors. Moreover, while all investors have reduced capital utilization between 2015 and 2020, public equity investors have reduced it relatively more. Public equity investors also increased utilization relatively less after 2021. We discuss the energy crisis that started in 2021 in more detail below.

[32] These effects are economically sizeable. One way to size economic magnitudes is to multiply emissions by an estimate of the social cost of carbon (SCC). For illustration, we provide a back-of-the-envelope number by following Adrian et al. [2022] that uses an average SCC of $80 per ton of CO2, the lower end of the range in Pindyck [2019]. The additional emissions owned by private investors due to reallocation (45MT) are worth $3.6 billion. Moreover, if state investors had reduced utilization as fast as public equity, the avoided emissions (22.5MT) would amount to $1.8 billion.

Technological differences: One potential concern is that differences between investors only reflects differences in technological obsolescence or efficiency of their initial capital.[33] We address this concern in two ways. First, we repeat the decomposition separately for subsamples of units of similar age in Figures IA.12, IA.13, and IA.14 in the Internet Appendix. We confirm that our key facts are not purely driven by composition effects across investors. There is nevertheless some intuitive heterogeneity across plants of different age: there is less reallocation among old units (which are more likely to be retired), and less difference in utilization across young units (which are less likely to be retired).

A second concern is that perhaps investors that are not closing plants are instead investing in technological upgrades that improve plant efficiency, and that our decomposition fails to capture this effect. To this end, we collect generator-level electricity output from ENTSO-e and construct a plant-level measure of emissions intensity by dividing yearly emissions by yearly output. We find that technology upgrades are rare in the coal sector: increases of 10% or higher efficiency occur with frequency of about 5% a year. Moreover, we find that in recent years these upgrades are concentrated within public equity investors, not in investors that keep plants open. Figures IA.15 and IA.16 in the Internet Appendix illustrate these results.

Additional results and robustness: For reference, Section IA.1 in the Internet Appendix contains six additional sets of results: (1) quantify the relative contribution of real reallocation versus financial reallocation to capital reallocation (i.e. how much of investors' sale of assets comes from trading plants vs. trading shares); (2) quantify permanent vs. temporary closures; (3) heterogeneity across countries; (4) heterogeneity within public equity investors (i.e. Blackrock and Vanguard vs. others); (5) differences between reallocation in debt vs. equity; (6) apply the decomposition to the U.S.

[33] Figure IA.11 in the Internet Appendix shows unit age across investor groups.

3.3 State Ownership of Brown Capital

States are strikingly large investors in coal and it is crucial to understand what drives their behavior. To this end, this section investigates the behavior of state investors and find striking differences between national, local and foreign state investors. We define a state investor as foreign if it is affiliated with a local or state government in a different country as the plant it owns. For example, if Swedish state-owned utility Vattenfall owns a plant in Germany, its ownership would count toward the foreign state investor share, but if it owns a plant in Sweden, it would count toward the domestic state investor share.[34] We also manually separate domestic investors between national (i.e. the Federal Republic of Germany) and local (i.e. the city of Mannheim).

Figure 5 shows foreign and local states have massively decreased their ownership share over our sample period. The foreign share fell by as much as 10 percentage points, from 15% to 4%, dividing their ownership share by three. The local states' share fell by a third, from 10% to 7%. In contrast, national states have massively increased their ownership share by 9 percentage points over the same period, from 22% to 31%. The relatively stability in the aggregate state investor share masks these sharp differences. Instead, our decomposition reveals what led to these diverging paths. Figure 6 shows that foreign and local state investors decreased their ownership purely via reallocation: they sold assets to private firms. National state investors in contrast were the slowest to scale down their existing plants, implying a large rise in their ownership share.

What are the underlying economic forces behind these dynamics? To start answering this question, we first delve into some of the (large) transactions that states have been involved with since 2016. We formalize the takeaways in a model in the next section.

The E.ON-Uniper Asset Split: In 2016, Germany energy giant E.ON finalized an asset split between its renewable and distribution services on the one hand and fossil fuel power generation (including coal plants) on the other, creating a large new publicly-traded entity

[34] Figure IA.26 in the Internet Appendix lists the largest foreign state investments in firms in our sample.

called Uniper. The CEO of E.ON said: "This liberates us from continually having to make compromises."[35] Who purchased Uniper once it became independent? The answer is the state-controlled Finnish utility Fortum. Figure IA.28 in the Internet Appendix shows how sharply the ownership dynamics of E.ON and Uniper diverged.[36] By 2022, Uniper is in fact fully state-owned, after a separate episode we describe in more detail below.

The Vattenfall Sale to EPH: The large drop in foreign state ownership is exemplified by the most striking case of Vattenfall. A Swedish state-owned utility, Vattenfall was the largest foreign state investor in coal in 2015, with notably a very large presence in Germany, accounting for nearly 10% of German coal emissions alone. In 2016, Vattenfall announced the sale of the vast majority of its German plants to the Czech private firm EPH. Vattenfall cited a willingness to improve its "corporate CO2 profile" and was gradually divesting from fossil fuels in accordance with a corporate commitment to CO2 neutrality by 2050. Nevertheless, the sale generated some backlash from commentators:

> *Asked whether greening Vattenfall's CO2 balance sheet would have any positive impact on the climate if it was achieved by simply selling its portfolio of lignite coal-fired power plants to another corporation, [CEO] Müller said the operation of coal-fired power plants was a matter of political policy and not within Vattenfall's bailiwick.*[37]

This seems to suggest that state investors put some (negative) value on climate externalities generated by brown assets, but only at home. In the parlance of Oehmke and Opp [2024], they seem to have a "narrow" mandate. For states, it is not difficult to imagine that their accountability lies mainly within the limits of their jurisdiction.

Local states have also been selling plants to private firms. A recent illuminating example is STEAG. This consortium of German municipal utilities agreed in August 2023 to sell its

[35]Source: "E.ON completes split of fossil fuel and renewable operations", The Guardian, January 4th, 2016; Link.

[36]Fortum eventually acquired a full controlling stake after a takeover bid was accepted in 2018. It initially purchased 50% of Uniper's stock, a share that increased to 75% in 2020. Source: "Finland's Fortum to gain control of Uniper in $2.5 billion deal", Reuters, October 8th, 2019; Link.

[37]Source: "Vattenfall sells German coal business", DW, April 18, 2016; Link.

business to private investor Asterion. STEAG operates six coal plants generating almost 5% of emissions in Germany. While only three months earlier the company made a public commitment to phase out the plants by mid-2026, the sale seems to have been a way to renege on that promise.[38] It is plausible that local governments have smaller incentives to internalize carbon externalities than national states.

Recent Wave of Nationalization: 2022 and 2023 witnessed some dramatic episodes of nationalization, driven by concerns over "energy security" and a shortage of alternatives to coal. Energy prices started to rise in the EU in 2021, and the sector entered fully-fledged crisis in 2022 with the Ukrainian conflict and the drastic decline of Russian gas imports. Ensued a large switch to coal power production that led to an *absolute increase* in coal emissions after years of steady decline with an increase in aggregate capital utilization during this period.[39]

When Uniper, which was spun off from E.ON, went bankrupt in 2022 after it could no longer afford to pay for Russian gas imports, it was rescued by the German government in order to keep it operating. This what eventually became the largest corporate bailout in German history. The nationalization costed 8B € to the German taxpayer. "Energy security" was cited as the primary motive for nationalization.[40] Germany also reverted some of its previous policies in favor of a coal phase-out.[41]

Moreover, the Polish government announced in 2023 that it will purchase all coal power plants held by publicly traded companies in Poland, spending close to $4 billion of taxpayer

[38] *"While STEAG's current municipal utility owners want to wash their hands of its polluting assets, they should be aware that the current sale could leave the company's sustainability commitments in shreds."* Source: "Germany's 2.6 € billion sale of STEAG may delay company's coal phase-out", Institute for Energy Economics and Financial Analysis, October 26, 2023; Link.

[39] The Internet Appendix describes the 2021-2022 rebound in more detail. Figure IA.9 shows the time series of aggregate coal emissions. Figure 1 shows that aggregate capacity has been declining throughout, so the rebound is driven by an increase in emission rates rather than new capacity additions.

[40] Source: "German Government Nationalizes Uniper in Move to Secure Energy Supply", New York Times, September 22, 2022; Link.

[41] Strikingly, it mandated the re-opening of plants it had previously subsidized to retire early. Source: "Germany Reopens Coal Plants Because Of Reduced Russian Energy", Forbes, July 8, 2022; Link. For example, Uniper was asked to extend the operations of its Heyden 4 plant with capacity of 875 MW in order to secure enough energy supply. The Heyden 4 plant had ceased operations after receiving a subsidy in a government tender in 2020. Source: "Uniper extends market operation of Heyden 4 and Staudinger 5 hard coal-fired power plants", Uniper, December 22, 2022; Link.

money in order to release the market pressure to close them.[42] The role of financial pressure was clear, with the government stating that "financial institutions have been limiting their involvement in financing entities with coal assets" and the CEO of PGE, the largest owner of coal plants in Europe, saying that the nationalization would help his firm with "obtaining financing for investments." The Polish government argued that the nationalization "will guarantee energy security."[43]

Takeaways: Typically, we tend to think of the role of states in the green transition (at least in the EU) through the lens of emissions targets or the introduction of renewable energy subsidies and carbon markets, i.e. a role that tends to reduce brown capital. Is there thus a "paradox" of rising domestic state ownership?

We argue that these episodes make it clear that it is crucial to understand the role of (short-run, local) social factors that states often balance with (long-run, global) climate externalities. These potential social factors include a desire to keep energy prices low ("energy security"), but also local jobs and income. Indeed, there is evidence that a transition away from fossil fuels can cause broad-based negative impacts on local communities historically built around these industries [Blonz et al., 2023, Du and Karolyi, 2023, Brey and Rueda, 2024]. This will be an important ingredient in our model below. Note however that we do not necessarily want to imply that states always behave as benevolent social planners. Moreover, states are also less affected by financial pressure relative to corporations, as they have deeper pockets with an ability to tax and borrow in their name. They might also be less concerned about the risk of tighter future regulation or taxes since they can make or influence the legislation.

Micro-data on employment and energy mix can help to make more concrete these potential social factors. With regards to employment, we can (coarsely) input the number of jobs directly associated with each power plant using data from the European Commission. Figure IA.29 in the Internet Appendix shows that states own approximately 50% of jobs throughout

[42]Source: "Poland's PGE, Enea, Tauron, Energa get state offers for coal assets", Reuters, July 15, 2023; Link.

[43]Source: "Polish government outlines offer to buy coal assets from state energy firms", Notes from Poland, July 17, 2023; Link.

our sample, while a decline of 7 percentage points in the public equity's share is matched with a rise in private investors'. Figure 4 re-estimates our main decomposition using plant employment instead of emissions, and find similar results. This is hardly surprising given that employment is naturally correlated with generating capacity.[44] We also see large variation in coal employment across countries. Figure IA.31 in the Internet Appendix shows that Poland stands out, especially when including coal mining jobs as well, with Germany being second albeit with some distance. There is also striking variation in the place of coal in the energy mix. While the EU average was just over 20% in 2015, Poland generated 80% of its electricity from coal, and Germany over 40%.[45] This suggests that in the cross-section of state investors, Poland should place significantly more weight on social factors relative to the rest of the EU, with Germany potentially in the middle. We will test this prediction when calibrating the model below.

It is also worth noting that, in a global context, countries that are expanding coal capacity, such as China and other emerging economies, tend to have significantly more state-owned enterprises than the EU and North America. At a global level, it is thus clear that the state ownership of coal assets is on the rise. Insights gleaned from our European evidence might thus be relevant more generally.

4 The Economics of Brown Capital (Re)Allocation

4.1 Overview

To understand the economics of brown capital reallocation, we develop a parsimonious model with one key difference with traditional models: externalities in production. The presence of externalities will generate a number of new insights. We then calibrate the model to the data and conduct some counterfactual analysis to draw implications for the rise of "green finance"

[44]Because the data is survey-based and not administrative we unfortunately cannot accurately measure layoffs beyond a decline in generating capacity.

[45]See this 2018 EU Commission report: EU coal regions: opportunities and challenges ahead.

and how it interacts with government intervention, in particular nationalization.

Our model has three main ingredients, informed by the evidence above. First, owners differ in how they value externalities associated with brown capital. Typical models instead focus on differences in productivity: some owners are better at operating a unit of capital. Our baseline model assumes away such productivity differences to focus on the role of externalities. Dispersion in asset valuation generates incentives to trade (regardless of whether they originate in productivity or externalities).

Second, there are financial frictions in the acquisition of new capital. While this is a common impediment to trade in traditional models, their effects are particularly interesting in the presence of externalities. Indeed, trade is not necessarily (socially) efficient if driven by externalities. Retiring units instead of selling them is necessary to decrease brown emissions. In that sense, impediments to trade, such as financial frictions, might improve capital allocation, instead of reducing it. This has the flavor of theories of the second-best.

Third, we take the structure of socially responsible investing seriously [Oehmke and Opp, 2024, Landier and Lovo, 2020, Green and Roth, 2021]. These theories have stressed the importance of the exact "mandate" of investors that value externalities. Investors might only care about externalities of the capital they currently hold, i.e a micro perspective (also referred to as a "narrow" or "value-alignment" mandate). On the other hand, investors might care about the effects of their capital allocation on aggregate externalities, i.e a macro perspective ("impact"). We will model the breadth of an owner's mandate directly through a specific parameter.

4.2 Setup

For tractability, we divide initial coal emissions into individual units (say 1MT of CO2) and model the decision of their owner to keep, sell or retire each of them individually over our sample period. For simplicity, we do not distinguish between hard retirements (closure) and soft retirement (leaving unit idle) in the baseline.[46] Units might differ in their profitability, with each unit i generating profits $\pi^i \sim F$. To focus on the role of externalities, we assume in the baseline model that all owners have the same profitability π^i for unit i.

Consider the problem of an owner (investor) endowed with a particular unit of brown capital. They can (i) keep operating it, (ii) sell it to a private buyer, or (iii) retire it. The owner's valuation of the asset is the sum of pecuniary profits and non-pecuniary externalities.

Pecuniary profits: The pecuniary profits from operating one unit are given by π^i. This represents productivity and cost of operating brown capital. Importantly, this includes any cost of carbon that is internalized, such as carbon pricing, competition from renewables, etc. Selling the unit to a private buyer (whose demand is derived below) generates a price P^i, which the owner takes as given. Retiring a unit yields zero profits.

Externalities: We augment the model to incorporate externalities. We first focus on (negative) climate externalities of operating brown capital. We assume that a private buyer does not value these externalities, while other owners incur a cost of $-\epsilon$ when operating a unit. Retiring the unit removes this cost. We interpret this potential valuation "wedge" for brown capital as resulting from stakeholder pressure (active shareholders, creditors, consumers, etc.) faced by public firms relative to private firms.[47] On the other hand, the impact of selling crucially depends on the owner's mandate. Selling generates a negative payoff of $-\theta\epsilon$, with θ. The parameter θ governs how *broad* the owner's mandate is [Oehmke and Opp, 2024]. If $\theta = 0$, they do not value externalities associated with assets they sell ("narrow mandate"). If $\theta > 0$, they have an "impact mandate:" they value (negatively) externalities from assets they sold and did not retire.

State investors differ from other investors in three important ways, but we defer the details of the state problem to a later section below.

Financial frictions: We assume private firms face financial frictions in acquiring brown

[46]See Internet Appendix IA.2 for a model extension with temporary closures. In the data, the decline in utilization comes from a mix of both.

[47]One example of stakeholders include creditors. Green and Vallee [2022] argue that banks' environmental commitments can cause closures of coal power plants.

capital. A competitive private owner purchasing unit i of brown capital at price P^i receives a payoff:

$$\pi^i - P^i$$

Absent financial constraints, the market clearing price is given by $P^{i*} = \pi^i$, a value that ignores externalities. However, we assume that the buyer has no cash on hand and must raise fund on capital markets. They can only pledge a fraction $\xi \leq 1$ of future profits to financiers, who ask for an expected return of $r \geq 1$. The unit can thus only be purchased if:

$$\xi\pi^i \geq rP^i \iff P^i \leq \frac{\xi}{r}\pi^i$$

The ratio ξ/r measures how loose financial frictions are. A lower ratio implies tighter constraints and an equilibrium price below π^i. As $\xi/r \to 1$, the price converges to its unconstrained value. Note also that this ratio measures the financial pressure faced by potential *buyers* of new capital; any pressure faced by existing owners is captured instead by the parameter ϵ.

4.3 Equilibrium: Baseline

In this section we described the equilibrium allocation of brown capital in the presence of different investors. For ease of exposition, we first focus on public equity investors and financially constrained private firms. We incorporate state investors in the next section.

4.3.1 Public equity investors

Consider a public firm owning some units with different profitability $\{\pi^i\}_i$. The decision to keep, sell or retire a unit will depend on two crucial parameters: (i) the market price P^i (ii) the breadth of its mandate θ. The payoff for each unit is given by:

- *Keep:* $\pi^i - \epsilon$

- *Retire:* 0
- *Sell:* $P^i - \theta\epsilon$

We first illustrate the key role played by investment mandates. Figure 7a shows the choice made by an owner with a mandate $0 < \theta < 1$. That means they (partially) internalize the externalities of units that they sell. In that case, they only keep units that are sufficiently profitable (π^i is high) when their price P is low enough. If the price is high enough, they prefer selling, and if the unit is not very profitable, they prefer to retire it.

Contrast this with the choices made by an owner with a narrow mandate $\theta = 0$. To be clear, this investor can strongly dislike emissions, but only for units that it keeps. Figure 7b shows that such an owner *never retires* units. When the market price is high relative to profitability, it sells these units to private firms. Intuitively, retiring gives a payoff of zero, while selling yields a non-negative price. When the price is low, that dissuades them from selling, but does not incentivize them to retire any units: they now prefer to keep some of the high-profitability units because the price is lower, but they still prefer selling low-profitability units. Even in the limit, they would rather sell these units for a penny rather than retire them. Narrow mandates thus only lead to pure reallocation and aggregate emissions do not fall. This is a key point: it is not enough that investors care about climate externalities, it crucially matters *how* they care.

4.3.2 Market equilibrium and the effects of financial frictions

We illustrate the market equilibrium for trading brown capital graphically in Figure 8. The demand curve from private firms is driven by financial frictions, while the supply curve is driven by investment mandates, as described previously.

This highlights the key role played by financial frictions. To this end, consider first the case in which they are absent. The top panel of Figure 8 shows the case of no financial frictions ($\xi/r = 1$). In that case, the market price is at its highest possible value for each unit $P^i = \pi^i$, and the private firms' demand is the 45 degree line. As a result, owners do not keep any units in equilibrium. Units are sold to a private buyer, with the exception of units with very low profitability which are retired. Most of the units are sold because the private buyer does not value externalities and has the highest valuation for the asset; there are thus large incentives to trade. The only limit to trade is the breadth of the owner's mandate. If $\theta > 0$, there is penalty incurred for selling brown capital instead of retiring it. This penalty is large enough only for units with low profitability.

The presence of financial frictions reduces selling and increase retirements. The bottom panel of Figure 8 shows that the price is lower than its unconstrained value of π^i, the owner now keeps some units with high profitability since selling is less attractive. But importantly, aggregate emissions also fall: the owner also retires more low-profitability units, as the price is no longer high enough to justify incurring a selling penalty. If financial constraints are strong enough, the price falls so much that the owner stops selling altogether and even more units are retired. Interestingly, note also that with narrow mandates ($\theta = 0$), tighter financial constraints have no effect on aggregate emissions, as they only redistribute ownership.

4.4 State ownership

States are large owners of coal power plants. We introduce states into our equilibrium model in such a way to rationalize two key facts: (i) domestic states scaled down less than public equity investors, (ii) foreign and local states sold more to private firms and scaled down less than other investors.

We assume states deviate from other owners in three important ways. First, they positively value social factors that are not valued as highly by other owners. Keeping a domestic unit open generates an additional payoff of $s > 0$ to the state. We interpret this potential valuation "wedge" for brown capital as driven by jobs and local activity associated with plants, but also stable energy prices for the rest of the economy ("energy security"). These could potentially be positive externalities under-valued by the private sector, but note that we do not want to imply that states necessarily act as a benevolent social planner. The framework allows for such social factors to be potentially mis-valued due perhaps to regulatory capture or other political considerations from the government,[48] and we will recover the overall magnitude of s from state investors' behavior in that data.

Second, different type of state investors might internalize climate externalities to varying degree. The empirical evidence suggests that foreign and local states have a lower θ than national states. Third, the state has "deep pockets" and we assume that financial constraints are not binding should it want to buy a plant from another owner.

These assumptions make it easy to rationalize the two facts above. The first assumption can explain why domestic states scaled down less than public equity investors. Valuing social factors reduces the payoff of retiring a plant. Figure 9 shows capital choice changes in the case of $s > 0$. The larger s, the more units are kept. Moreover, the second assumption can explain why foreign and local states sold more to private firms and scaled down less than other investors. As discussed above, an owner with a low θ has a high propensity to sell rather than retire units.

4.5 Model calibration

We calibrate the model using our microdata. Our decomposition of ownership dynamics can be used to identify the key parameters. To take the model to the data, we make the following additional assumptions. Profitability is normally distributed $\pi^i \sim N(\bar{\pi}, 1)$. Since payoffs are unit-less, there is one degree of freedom and we normalize the standard deviation of profitability to unity.[49] We allow for different breadth θ of mandates across public equity investors, national state investors, and pooled foreign/local state investors. To reduce the effects of different technologies across plants, we only include data for plants between the

[48]For the example, in the context of Germany's energy policy, Jarvis et al. [2022] estimate that the decision to phase-out nuclear power had a large social cost.

[49]The model can be easily extended such that the mean profitability depends on the age of the plant.

10th and 90th percentile of plant age.[50] To isolate the impact of nationalization to the counterfactual analysis, we also do one modification of the 2022 year of data in by reversing the Uniper nationalization.

Table 1 summarizes the calibration of the baseline model. There are seven parameters to estimate, which are jointly identified by seven moments from our decomposition. Section IA.3 in the Internet Appendix describes the underlying estimating equations and mapping to the model in more detail, including proofs that the model parameters are identified.

We find reasonable values for model parameters, reported in the last column. There has been a large aggregate decline in profitability of coal since 2015, implying that about 25% of initial capital is no longer profitable.[51] The valuation ϵ of climate externalities is large (25% larger than average plant profitability). National states however strongly value social factors, with s being in fact almost as high as climate externalities ϵ. Financial constraints are binding, with the ratio ξ/r being below unity. The magnitudes of investor mandates θ are also intuitive. Foreign and local state investors have narrower mandates relative to national states and public equity investors.

Extension: We complement the baseline calibration with an extension that investigates some of the (admittedly limited) cross-country and time variation in the data. Specifically, we extend the calibration along two dimensions. First, we allow heterogeneity among domestic state investors and re-calibrate θ and s separately for Poland, Germany, and the rest of the EU (pooling national and local states). Second, we explicitly study the reversal due to the the energy crisis by comparing the estimates when the sample ends in 2022 versus 2020.

Table IA.4 in the Internet Appendix summarizes the results. First, we find important cross-sectional differences across state investors. In the pre-energy crisis sample, s is strikingly large in Poland, being twice as large as climate externalities (0.95 vs. 0.47), signficantly larger than

[50]Table IA.3 in the Internet Appendix shows robustness to using a more homogeneous sample of plants with age between the 33th and 66th percentiles. Estimated parameters are very similar to our baseline sample. Recall also that Figure IA.13 in the Internet Appendix shows that applying our decomposition in that sample yield very similar results than on the entire sample.

[51]If we use data only up to 2020, as much as 43% of initial capital would no longer profitable. This highlights how much the recent energy crisis has increased the profitability of coal.

in other regions. This is consistent with these countries actively implementing energy policies that favors alternatives to coal (Russian gas, nuclear, renewables). Germany in particular is estimated to have an s essentially equal to zero, in line with the environmental policy to phase-out coal by a reliance on gas. However, we observe a drastic increase in s for all states once we include data up to 2022. The case of Germany is particularly striking, with s increasing from zero to 0.38, now level to other EU countries outside of a Poland. Germany's plan to rely on Russian gas to replace nuclear and coal power generation was severely disrupted with the start of the Ukrainian-Russian conflict in 2022. We also find that the profitability of coal is dramatically higher in this sample. Overall, these parameter values are consistent with a reduction in the supply of alternatives to coal and salient "energy security" concerns in recent years. We view this extension as additional evidence supporting the underlying economics of the model.

5 Implications

In this section, we use the baseline calibration of the model to illustrate some of the key economic implications of brown capital reallocation. In particular, we focus on the effects of the rise of "green finance," understood broadly as the increased attention paid by financial institutions to the carbon content of their capital allocation. We argue that, while "green finance" can decrease aggregate emissions, the existence of states as investors is an important limit.

5.1 The rise of "green finance"

Through the lens of the model, a more climate-conscious financial sector has two effects. First, it tightens financial constraints for potential buyers. As more financial institutions are conscious of the emissions of their portfolio, it becomes increasingly difficult to finance brown assets. This would lower the ratio ξ/r, either by increasing the financiers' expected rate of return and/or reducing the pledgeability of brown assets (i.e. worse collateral). Second, it can also increase the share of investors with broad mandates, which take a macro perspective. Indeed, they have been many campaigns to convince investors not to sell assets to reduce their carbon footprint but instead actually scale down (exercise "voice" over "exit").[52]

In equilibrium, we have seen how tighter financial constraints reduce aggregate emissions because they depress the market price of brown capital, making selling less attractive relative to scaling down a plant. Broad mandates have similar effects of making selling less appealing. In that sense, the rise of "green finance" can reduce aggregate emissions.

Quantitatively, both forces appear to be important. Indeed, in our calibration, removing financial frictions ($\xi/r = 1$) increases aggregate emission by 9 percentage points. Having instead narrow mandates has similarly large effects. In the counterfactual in which public equity investors have mandates as narrow as foreign/local states ($\theta = 0.33$), aggregate emissions are 6pp higher. Including both effects lead to 12pp more emissions, slightly crowding each other out.

5.2 Government intervention and nationalization

Importantly, we argue that "green finance" not only affects firms' decisions, but also the state's incentives to intervene. In our model, there are two reasons why the state might potentially want to step in: climate externalities and social factors, both of which are potentially undervalued by the private sector. We consider each in turn.

Climate externalities: The state might prefer to have some units retired rather than being sold to private buyers, for example by subsidizing plant closure. The economics of the model shows that incentives to intervene are largest when three conditions are met. First, climate externalities are large relative to social factors ($s << \epsilon$), such that there are many units that the state would prefer to retire. Second, financial frictions are low (ξ/r is close to

[52]For instance, the NGO Beyond Fossil Fuels calls for pushing "fossil fuel companies [...] towards a rapid and just energy transition that includes commitments to close **(not sell)** coal plants by 2030." Source: https://beyondfossilfuels.org/finance-and-corporates/. Emphasis added.

one). Third, owners do not internalize climate externalities when they sell (θ is low). In these cases, the incentives for firms to "exit" are the largest. Intuitively, the rise of "green finance" can thus help correct climate externalities and substitute for government intervention to retire plants.

In our calibration, we actually find no units that the state would like to close due to climate externalities. This is due to two factors. First, states highly value social factors, by almost the same magnitude as climate externalities. Second, financial frictions are high and public equity investors have a broad enough mandate, such that they often prefer to retire units rather than selling them to private firms.

Social factors: Interestingly, the picture looks very different when considering potential social factors. When the state values aspects such as "energy security" relatively more than other investors, that introduces the possibility of nationalization: the state might want to purchases a unit that another owner plans to retire. Interestingly, in our model nationalization tend to be cheaper than subsidies to keep units open.[53]

Through the lens of our model, the incentives to nationalize are the largest when: (i) social factors are highly valued relative to pecuniary profits; as well as (ii) financial frictions are tight; and (iii) firms' mandate are broad, such that firms' incentives to retire are large. In that sense, the rise of "green finance" can actually increase the incentives to intervene because of social factors.[54]

In our calibration, we find that these effects are substantial. 48% of units retired by public equity investors are potential targets for nationalization (representing 27% of initial emissions).

[53]Subsidies tend to be more expensive than nationalization as long as owners do not fully internalize climate externalities ($\theta^O < 1$). Intuitively, in that case an owner requires less compensation to sell a unit rather than keep operating it. To see this, a subsidy $\Delta > 0$ convinces an owner to keep a unit open if $\pi^i - \epsilon^O + \Delta > 0$ (taking the subsidy must also be more attractive than selling, but this constraint is slack for the type of units that would be retired absent subsidies). The lowest subsidies that can be offered is thus $\Delta = \epsilon^O - \pi^i$, which is positive since the owner would retire it without subsidies. The cost to the state is thus $\Delta = \epsilon^O - \pi^i$, which is greater than the net cost of buying a unit (at price $\hat{P} = \theta^O \epsilon^O$) of $\theta^O \epsilon^O - \pi^i$. This can potentially explain why the recent wave of nationalization was not implemented as new subsidies. In our calibration, subsidies would in fact be singficantly more expensive than nationalization for the median target, given the moderate level of public equity investors' mandate θ.

[54]There is a potential link with arguments that "E" is being over-weighted relative to "S" within the ESG framework [Saul, 2022].

However, incentives to intervene are smaller in the counterfactual with no financial frictions and narrow mandates. In that case, the number of targets is reduced by almost two-thirds.[55]

The existence of state investors is thus an important limit to the ability of "green finance" to reduce aggregate emissions. Indeed, the state has incentives to undo some of the effects of climate-conscious investors if it believes they do not sufficiently value social factors. This is consistent with the narrative of the recent nationalization in Poland.[56]

Permanent vs. temporary closure: What if firms have the possibility to only temporary scale down their units, preserving the option value of turning them back on later? Section IA.2 in the Internet Appendix shows that this reduces, but crucially does not eliminate, incentives for the state to nationalize plants. This is because the private sector has still some incentives to permanently retire units. Intuitively, for the least profitable plants, the option value is not large enough to outweigh the costs of temporarily turning off a plant, whether they are pecuniary cost (i.e. fixed operating cost) and non-pecuniary (i.e. the possibility of future emissions). A larger cost of climate externalities ϵ exacerbates these incentives to permanently retire units.

5.3 The profitability of brown capital

Pigouvian principles suggest that the most natural way to phase-out carbon-intensive capital is to reduce its profitability, via a variety of economic mechanisms (i.e. a carbon or fossil fuel tax). We argue that these policies might have smaller short-term effects than typically thought because because they do not only influence private sector investors but also *state investors'* incentives to intervene. Concrete some states have incentives to "get in the way"

[55]Note also that the state must pay a premium over the market price P^i. Indeed, a price higher than the market is necessary to convince an owner wanting to retire to change its mind. Assuming that the state can make a take-it-or-leave-it offer to its owner, the minimum price that must be offered is $\hat{P^i} = \theta\epsilon$. In our calibration, the premium of the medium target is 79% of its market price. The premium is high because public equity investors both highly dislike climate externalities and have a broad mandate, making them reluctant to sell. However, when financial frictions are tight, the market price is low to begin with.

[56]Note again that we do not want to imply that the Polish government is a benevolent social planner, but rather that it values factors that climate-conscious private investors might value less.

with the looming threat of nationalization.

Through the lens of our model, we can study a sudden decline in profitability π without significant change in s. For example, a sharp rise in carbon pricing is likely to reduce the profitability of coal without alternatives growing equally fast, as clean power investment takes time to build. While it increases incentives for firms to quickly retire units, it would also preserve incentives for the state to intervene to prevent retirements. In our calibration, decreasing average profitability by 50% without changing s leads a 12pp reduction in emissions, but very little reduction in the incentives to nationalize units. This is perhaps part of the rationale for "gradualism" in clean energy policies.

For illustration, in a counterfactual in which average profitability and the social value of brown capital s *both* decline by 50% , aggregate emissions falls by an additional 14pp (relative to 50% in the data). In addition, the effects on reducing incentives to nationalize are equally large: the share of potential targets would be two-third smaller and fall by 28 percentage points. This scenario is consistent with a more mature renewable power generation and storage network that competes with existing coal plants.[57]

5.4 Open questions

The findings of this paper suggests at least three avenues for future research.

First, how does state ownership of brown assets interact with more traditional tools such as Pigouvian taxation or regulation? We have sketched a few ideas, but more work is needed given our evidence that state ownership has real effects on plant utlization and emissions. Another recent example is Baranek et al. [2021] that shows that state-owned energy firms in Italy do not internalize carbon pricing in their production decision. Given the rise in

[57] This is the mirror image of an "energy crisis." A sudden reduction in alternatives to coal (i.e. ending gas imports) would likely have two effects. First, an increase in electricity prices would increase the profitability of coal π, reducing incentives for firms to retire units. Second, an increase in s would also increase incentives for the state to both stop paying to retire units and for nationalizing more units. This is consistent with the experience of Germany in 2022 described above. In our calibration, increasing average profitability and s by 30% would increase aggregate emissions by 8pp, and the share of potential targets for nationalization would increase by 16pp (or about 5% of 2015 emissions).

state ownership documented in our paper, this result has important implications for the pass-through of traditional carbon policies.

Second, *quantitatively* how large are social benefits of keeping brown capital operating? While there is a large literature on quantifying the the social cost of carbon (see for instance Adrian et al. [2022]), what is for instance the social value of "energy security"? This is a key question given that many policy-makers are seemingly acting today as if that value is very large.

Third, is the capital diverted away from fossil fuels actually funding alternative green capital and jobs *locally*? This matters since unequal distributionial effects of the energy transition can lead some states to resist it. This is especially salient in times and regions with a high share of "brown" jobs or high risk of energy shortages, as experienced by many parts of the world in recent years.[58] At the same time, "brown" countries do not necessarily have the highest renewable power potential, e.g. wind and solar might operate at higher efficiency in Denmark, Spain, or Italy as opposed to Poland. Historically, providing new employment opportunities to fossil fuel communities has also proven challenging.

External validity: Our analysis focuses on coal power plants in Europe. Do the underlying economics generalize to other settings? While every case is different, we conclude by drawing a brief comparison with two other settings: coal in Asia, and oil and gas in the West. First, in sharp contrast to the West, coal has been expanding rapidly in Asia, even in recent years. In 2023 alone, China has added over three times more coal capacity than what was retired in the EU, the UK, and the US combined, while India, Indonesia, Vietnam and other emerging economies have also built new coal plants.[59] Importantly, state-owned enterprises are almost entirely responsible for these investment in countries that still have large energy needs. At some level, these dynamics resonate with some of the forces we uncovered in Europe. The case of oil and gas in the West is also interesting. These fossil fuels seem to be more

[58]The few cases of Just Energy Transitions Partnerships in emerging economics are a case in point [Adrian et al., 2022]. For example, in 2022 some western countries agreed to help finance the development of renewables in Indonesia conditional on a commitment to phase out coal.

[59]See the Global Energy Monitor report.

profitable in addition to being less carbon-intensive than coal. Gas is also sometimes framed as important in the transition away from coal,[60] while alternatives to petroleum are currently limited for some industries and forms of transportation. This would suggest a smaller ownership share by states, which is in line with what we observe (at least in the West). Perhaps this will change going forward as "green finance" puts more focus on these sectors after coal has been largely phased out. If that ever happens, the large share of jobs, revenues, and electricity production from these fossil fuels might lead to dynamics that echo what we currently see in the coal sector. More work is nevertheless needed to better understand implications for different regions and forms of brown capital.

6 Conclusion

This paper investigates who owns coal power plants by merging micro-level data on firms' plant ownership in Europe with firms' shareholder data. In spite of a sharp increase in the private ownership of coal, we find no evidence for public equity investors exercising "exit" and selling brown assets to other investors. Instead, the large decline in their coal ownership since 2015 is due to them retiring plants, not selling them. In contrast, we highlight the crucial role played by a third, large group: state investors. Foreign and local states were the ones that sold to private firms, while national states were the slowest at scaling down their plants.

We illustrate the economics of brown capital reallocation through a model that incorporates production externalities. We find that the rise of "green finance" can decrease aggregate emissions, but that the existence of states as investors that care about other social factors (e.g. jobs, "energy security") is an important limit. A more thorough understanding of the drivers of capital reallocation across brown and green sectors and the role of the state is an important avenue for future research.

[60]For instance, the European Commission has included gas under the "transitional activity category" of the Taxonomy Regulation to "allow us to accelerate the shift from more polluting activities, such as coal generation, towards a climate-neutral future, mostly based on renewable energy sources."

References

M. T. Adrian, M. P. Bolton, and A. M. Kleinnijenhuis. *The great carbon arbitrage.* International Monetary Fund, 2022.

P. Alves Dias, K. Kanellopoulos, H. Medarac, Z. Kapetaki, E. Miranda-Barbosa, R. Shortall, V. Czako, T. Telsnig, C. Vazquez-Hernandez, R. Lacal Arantegui, et al. Eu coal regions: opportunities and challenges ahead. *European Commission, Joint Research Centre: Petten, The Netherlands*, pages 20–32, 2018.

A. Andonov and J. D. Rauh. The shifting finance of electricity generation. *Available at SSRN*, 2022.

C. Arkolakis and C. Walsh. Clean growth. Technical report, National Bureau of Economic Research, 2023.

J. Azar, M. Duro, I. Kadach, and G. Ormazabal. The big three and corporate carbon emissions around the world. *Journal of Financial Economics*, 142(2):674–696, 2021.

M. Baker, M. L. Egan, and S. K. Sarkar. How do investors value esg? Technical report, National Bureau of Economic Research, 2022.

B. Baranek, F. Boffa, and J. Kastl. Revisiting cap-and-trade in presence of publicly owned polluters: The case of italy 2006-2018. 2021.

T. Berg, L. Ma, and D. Streitz. Out of sight, out of mind: Divestments and the global reallocation of pollutive assets. *Available at SSRN 4368113*, 2023.

J. Berk and J. H. Van Binsbergen. The impact of impact investing. 2021.

J. Blonz, B. R. Tran, and E. E. Troland. The canary in the coal decline: Appalachian household finance and the transition from fossil fuels. Technical report, National Bureau of Economic Research, 2023.

B. Brey and V. Rueda. The death of king coal: industrial decline during childhood and lifetime well-being. *CEPR Working Paper*, 2024.

M. Brière, S. Pouget, and L. Ureche-Rangau. Blackrock vs norway fund at shareholder meetings: institutional investors' votes on corporate externalities. *Available at SSRN 3140043*, 2018.

M. Briere, S. Pouget, M. C. Schmalz, and L. Ureche-Rangau. (why) do(n't) universal investors vote to curb climate change? *Available at SSRN 4245612*, 2023.

E. Broccardo, O. Hart, and L. Zingales. Exit versus voice. *Journal of Political Economy*, 130(12): 3101–3145, 2022.

A. Chen and M. Wittry. Production and externalities: The role of ownership structure. *Working Paper*, 2024.

E. Dimson, O. Karakaş, and X. Li. Active ownership. *The Review of Financial Studies*, 28(12): 3225–3268, 2015.

D. Du and S. A. Karolyi. Energy transitions and household finance: Evidence from us coal mining. *The Review of Corporate Finance Studies*, 12(4):723–760, 2023.

R. Duchin, J. Gao, and Q. Xu. Sustainability or greenwashing: Evidence from the asset market for industrial pollution. *Available at SSRN*, 2022.

A. L. Eisfeldt and Y. Shi. Capital reallocation. *Annual Review of Financial Economics*, 10:361–386, 2018.

M. Giannetti, M. Jasova, M. Loumioti, and C. Mendicino. "glossy green" banks: The disconnect between environmental disclosures and lending activities. 2023.

S. Giglio, M. Maggiori, J. Stroebel, Z. Tan, S. Utkus, and X. Xu. Four facts about esg beliefs and investor portfolios. Technical report, National Bureau of Economic Research, 2023.

D. Green and B. Roth. The allocation of socially responsible capital. *Available at SSRN 3737772*, 2021.

D. Green and B. Vallee. Can finance save the world? measurement and effects of coal divestment policies by banks. *Measurement and Effects of Coal Divestment Policies by Banks (April 8, 2022)*, 2022.

S. M. Hartzmark and K. Shue. Counterproductive sustainable investing: The impact elasticity of brown and green firms. Technical report, Working Paper, Boston College, 2023.

I. Ivanov, M. S. Kruttli, and S. W. Watugala. Banking on carbon: Corporate lending and cap-and-trade policy. *Available at SSRN 3650447*, 2023.

S. Jarvis, O. Deschenes, and A. Jha. The private and external costs of germany's nuclear phase-out. *Journal of the European Economic Association*, 20(3):1311–1346, 2022.

M. T. Kacperczyk and J.-L. Peydró. Carbon emissions and the bank-lending channel. *Available at SSRN 3915486*, 2022.

M. E. Kahn, J. Matsusaka, and C. Shu. Divestment and engagement: The effect of green investors on corporate carbon emissions. Technical report, National Bureau of Economic Research, 2023.

R. S. Koijen, R. J. Richmond, and M. Yogo. Which investors matter for equity valuations and expected returns? Technical report, National Bureau of Economic Research, 2020.

A. Landier and S. Lovo. Esg investing: How to optimize impact? *HEC Paris Research Paper No. FIN-2020-1363*, 2020.

A. Lanteri and A. A. Rampini. Financing the adoption of clean technology. 2023.

I. Luneva and S. Sarkisyan. Where do brown companies borrow from? *Available at SSRN 4249210*, 2022.

M. Oehmke and M. M. Opp. A theory of socially responsible investment. *Review of Economic Studies*, page rdae048, 2024.

R. S. Pindyck. The social cost of carbon revisited. *Journal of Environmental Economics and Management*, 94:140–160, 2019.

P. Sastry, D. Marques-Ibanez, and E. Verner. Business as usual: Bank climate commitments, lending, and engagement. *Lending, and Engagement (December 13, 2023)*, 2023.

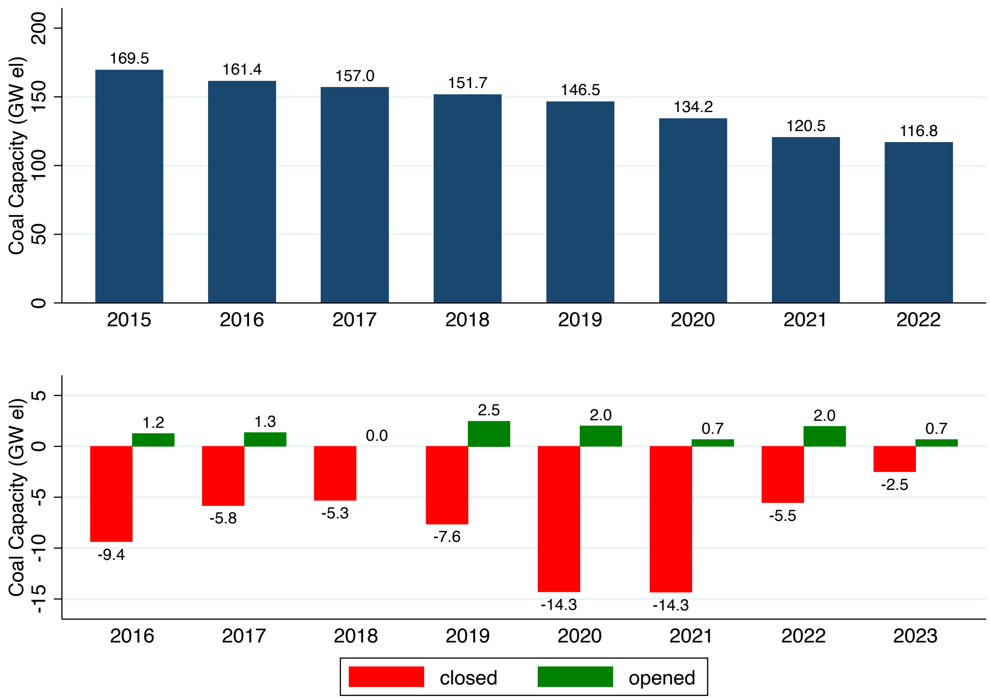
J. Saul. Fixing the s in esg. *Stanford Social Innovation Review*, 2022.

S. A. Shive and M. M. Forster. Corporate governance and pollution externalities of public and private firms. *The Review of Financial Studies*, 33(3):1296–1330, 2020.

P. Van der Beck. Flow-driven esg returns. *Swiss Finance Institute Research Paper*, (21-71), 2021.

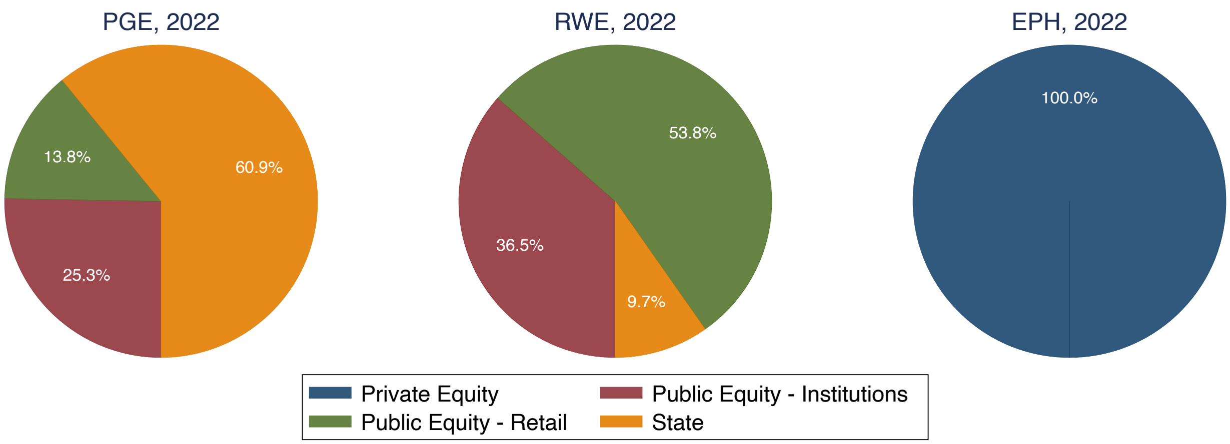
S. Walz. Do banks care about the environment? estimating the greenium and implications for bank lending. *Estimating the Greenium and Implications for Bank Lending (August 12, 2022)*, 2022.

Figure 1: Coal Capacity of Open Plants in the EU, 2015-2022



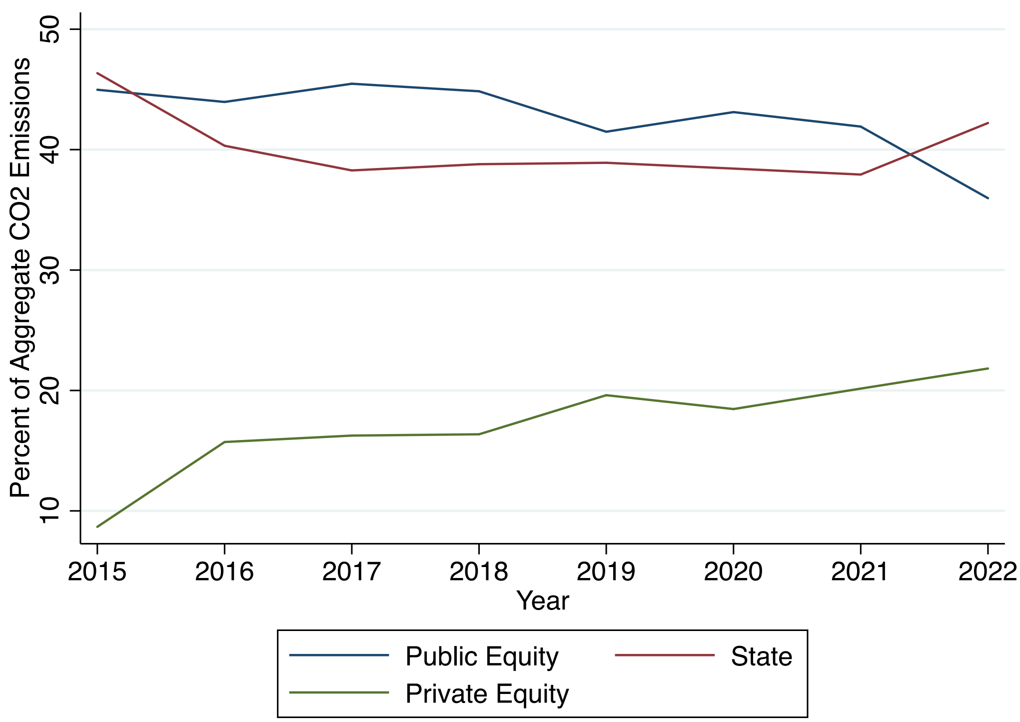
The top panel shows the aggregate coal capacity across all open coal plants in the EU and UK, as recorded at the end of each year from 2015 to 2022 in the BFF data. The bottom panel shows increases or decreases in aggregate coal capacity in each year, which may result from the opening or closure of entire coal plants or operational units within coal plants. The aggregate coal capacity for year t is equivalent to the aggregate coal capacity for year $t-1$, adding any coal capacity opened in year t and subtracting any coal capacity closed in year t.

Figure 2: Investor Composition for PGE, RWE, and EPH, 2022



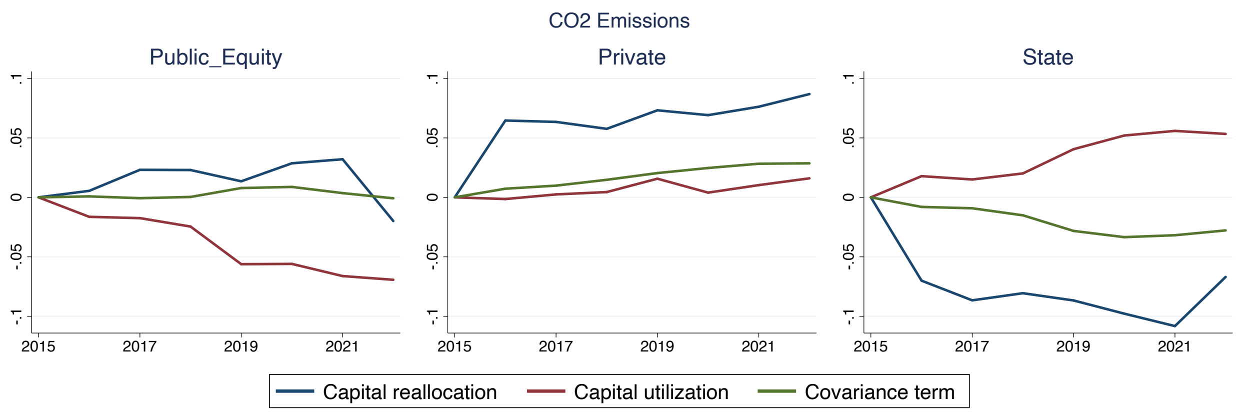
Shares of the four investor categories are based on the investor composition of each firm as of December 31, 2022. PGE and RWE are publicly-traded firms, whose shareholder information are from Capital IQ. EPH is entirely privately-owned.

Figure 3: Ownership of CO2 Emissions in the EU, 2015-2022



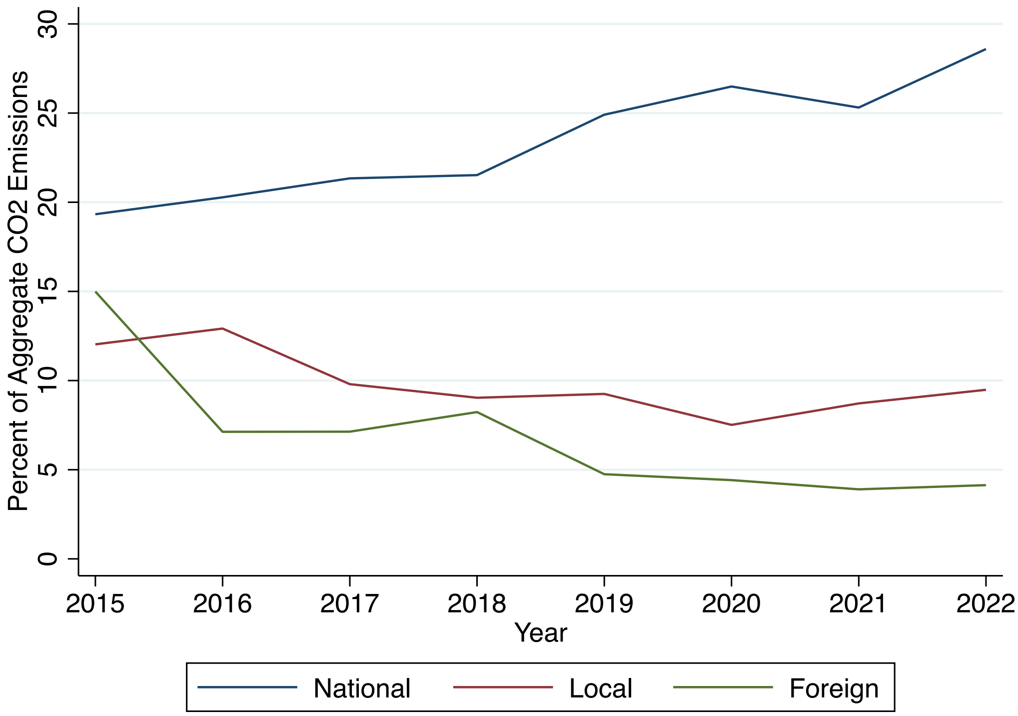
This figure shows the share of annual aggregate CO2 emissions in the EU owned by each of three main investor categories. Coal plant data are from Beyond Fossil Fuels. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research.

Figure 4: Capital Reallocation versus Capital Utilization



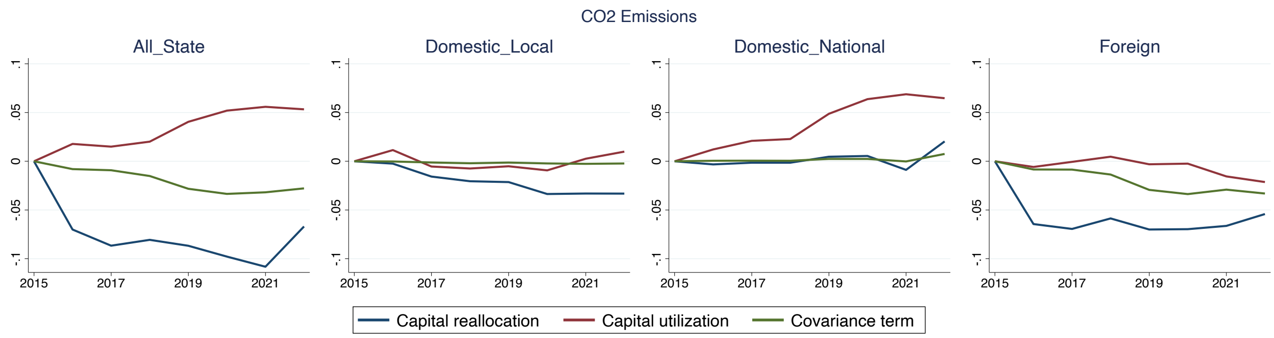
Each panel shows the three terms in the decomposition in equation (2) for a given investor group, across all plants in the EU over the period 2015-2022. The *Public Equity* category reflects retail or (non-state) institutional investors in publicly traded companies. The *Private* category reflects non-state owners of private companies. The *State* category reflects state-owned shares in both public and private companies. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure 5: Ownership of CO2 Emissions Across State Investors in the EU, 2015-2022

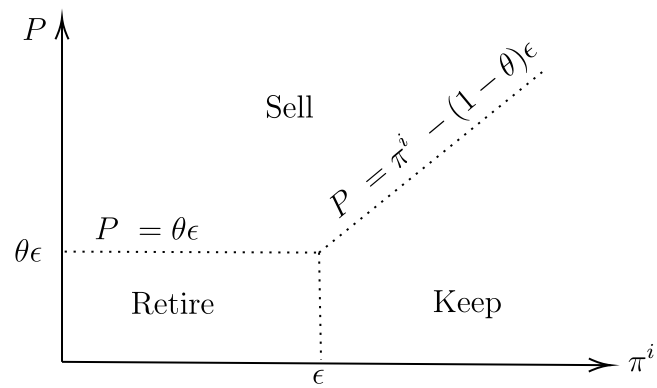


This figure shows the annual percentage of aggregate CO2 emissions that is owned by domestic national, local and foreign investors. A state investor in a plant is considered domestic if it is affiliated with a local or state government that is located in the same country as the plant it owns. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

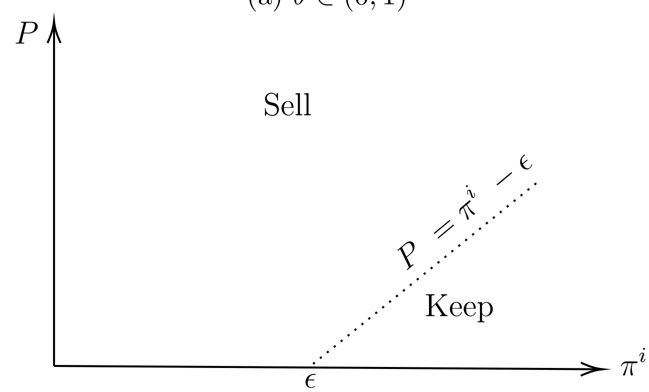
Figure 6: Capital Reallocation versus Capital Utilization: State Investors



Each panel shows the three terms in the decomposition in equation (2) for a given investor group, across all plants in the EU over the period 2015-2022. The *All State* category reflects all state investors. The *Domestic* category reflects only domestic state investors. A state investor in a plant is considered domestic if it is affiliated with a local or state government that is located in the same country as the plant it owns. The *Foreign* category reflects only foreign state investors. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

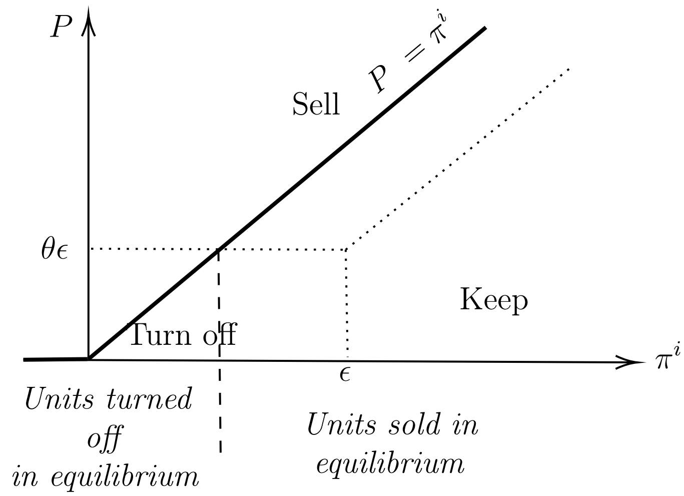


(a) $\theta \in (0, 1)$

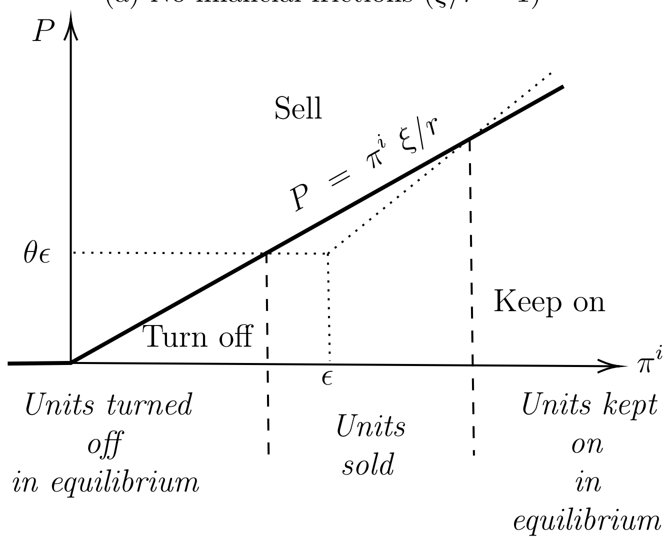


(b) Narrow mandate: $\theta = 0$

Figure 7: Capital choice



(a) No financial frictions ($\xi/r = 1$)



(b) High financial frictions ($\xi/r < 1$)

Figure 8: Equilibrium for different levels of financial frictions ξ/r

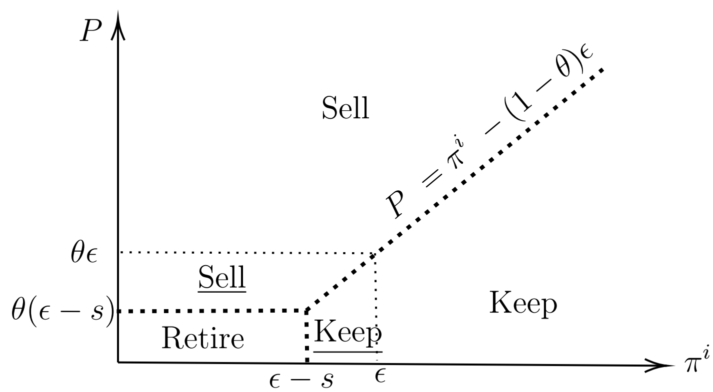


Figure 9: Capital choice for state investor with $s > 0$

	Parameter	Estimate
1	Average profitability of units $\bar{\pi}$	0.62
2	Cost of climate externalities ϵ	0.78
3	Benefit of social factors s	0.70
4	Mandate of public equity investors θ^P	0.55
5	Mandate of national state investors θ^{DS}	0.40
6	Mandate of foreign/local state investors θ^{FLS}	0.33
7	Financial frictions ξ/r	0.55

Table 1: Model calibration

Internet Appendix for Brown Capital (Re)Allocation

IA.1 Additional Empirical Results

Real vs. Financial Capital Reallocation: We can also use our data to quantify the relative contribution of real reallocation versus financial reallocation to capital reallocation, i.e. how much of investors' sale of assets comes from trading plants vs. trading shares. Formally, investor group g ownership of plant i is the product of ownership of firm f and firm f's ownership of plant i: $\omega^g_{i,t} = \sum_f \omega^g_{f,t}\omega^f_{i,t}$.

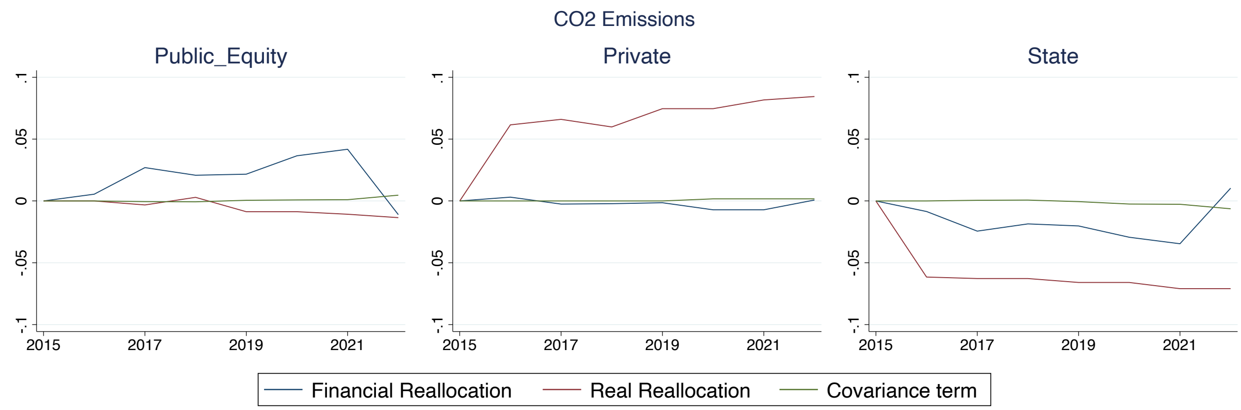
We can thus further decompose the capital reallocation term between financial reallocation (across investors) and real reallocation (across firms), plus a covariance term:

$$\begin{aligned}\sum_i (\omega^g_{i,t} - \omega^g_{i,t_0})\frac{e_{i,t_0}}{E_{t_0}} = \quad & \underbrace{\sum_i \sum_f (\omega^g_{f,t} - \omega^g_{f,t_0})\omega^f_{i,t_0}\frac{e_{i,t_0}}{E_{t_0}}}_{\text{financial reallocation (trade shares across investors)}} \\ & + \underbrace{\sum_i \sum_f \omega^g_{f,t_0}(\omega^f_{i,t} - \omega^f_{i,t_0})\frac{e_{i,t_0}}{E_{t_0}}}_{\text{real reallocation (trade plants across firms)}} \\ & + \underbrace{\sum_i \sum_f (\omega^g_{f,t} - \omega^g_{f,t_0})(\omega^f_{i,t} - \omega^f_{i,t_0})\frac{e_{i,t_0}}{E_{t_0}}}_{\text{covariance term}}\end{aligned} \tag{3}$$

Figure IA.1 reveals that there were diverging patterns of real versus financial reallocation across investors. Private firms bought plants from states, while until 2022 public equity investors bought shares from states. We discuss the 2022 reversal in more detail below in the context of (re)nationalizing brown assets.

Permanent versus temporary closure: Emissions of a plant can decrease either because of (i) permanent closure (a decline in generation capacity) and/or (ii) temporary scaling down (a decline in the emission rate per unit of open capacity). In the aggregate, it is clear that both channels matter, since emissions declines by about 50% but capacity only decreased by about 25%. Figure IA.17 in the Internet Appendix shows that is generally true for investors

Figure IA.1: Financial Reallocation versus Real Reallocation



Each panel shows the three terms in the decomposition in equation (3) for a given investor group, across all plants in the EU over the period 2015-2022. The *Public Equity* category reflects retail or (non-state) institutional investors in publicly traded companies. The *Private* category reflects non-state owners of private companies. The *State* category reflects state-owned shares in both public and private companies. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

groups that decreased their emissions.[61] There is a rebound in emissions post-2020 that we discuss in more detail below.

Across Countries: To investigate geographical differences, we separately look at ownership dynamics in three regions: Germany, Poland (the two largest emitters of CO2), and the rest of the EU. Figures IA.18, IA.19 and IA.20 in the Internet Appendix illustrate the results. We find that virtually all reallocation in Europe, whether of plants or shares, occurred for German plants. Moreover, unlike in Poland, public equity investors in German plants did

[61]For this, we decompose the capital utilization term in three further terms, with the modification that we measure plant scale by the level of its emission ($e_{i,t}$) rather than its share relative to the total ($e_{i,t}/E_{i,t}$). Formally, the emissions of plant i are the product of its capacity k (driven by closure/opening of units) and emission rate r (how much CO2 per unit of capacity): $e_{i,t} = k_{i,t} r_{i,t}$. The capital utilization term can thus itself be divided into an exact sum of three terms:

$$\sum_i \omega^s_{i,t_0}(e_{i,t} - e_{i,t_0}) = \underbrace{\sum_i \omega^s_{i,t_0}(k_{i,t} - k_{i,t_0}) r_{i,t_0}}_{\text{capacity changes}} + \underbrace{\sum_i \omega^s_{i,t_0} k_{i,t_0}(r_{i,t} - r_{i,t_0})}_{\text{emission rate changes}} + \underbrace{\sum_i \omega^s_{i,t_0}(k_{i,t} - k_{i,t_0})(r_{i,t} - r_{i,t_0})}_{\text{covariance term}} \tag{4}$$

not scale down faster than other investors. The largest decline in public equity ownership is observed in the rest of the EU, with a decline of almost 20 percentage points, almost entirely driven by a decline in utilization.

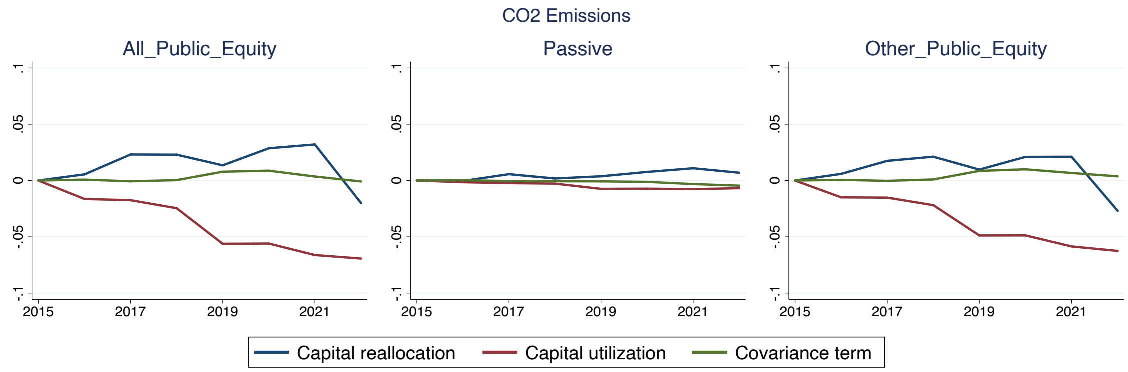
Heterogeneity Within Public Equity Investors: We can also look at ownership dynamics within public equity investors, since they have experienced a striking decline in their ownership share. In particular, large passive investors like Blackrock and Vanguard have faced significant and repeated pressure in the past decade to account for carbon emissions in their portfolios. One might expect that such "universal" investors might have played a large role, in part because they often claim to use their voice to influence corporate management due to a lesser ability to re-allocate their equity portfolio (making "exit" difficult).

To investigate this question, we separate the public equity investor group between passive institutional investors and the rest, using investor classifications from Capital IQ. Applying our decomposition to these subgroups, we see that the decline in utilization is not in fact more pronounced for passive institutional investors. Figure IA.2 illustrates this heterogeneity: passive investors do not drive the negative capital utilization term over our sample period. In terms of aggregate ownership, Figure IA.21 in the Internet Appendix confirms that the share of passive investors has been extremely stable at 5% over the entire period. The aggregate decline in public equity ownership of 9 percentage points is *entirely* driven by other equity investors, whose share has fallen by from 40% to 31%. While large passive investors generally tend to vote in favor of managing climate externalities in firms they invest in [Briere et al., 2023], our evidence revealed that this had no noticeable effect on the coal power production industry, the most carbon-intensive sector in the world. The rise of large "universal investors" over the past decades might thus not have accelerated the phase-out of brown capital.[62]

Debt vs. Equity: This paper focuses on equity ownership, but we provide a brief analysis

[62] In recent years, BlackRock and especially Vanguard seem to have stepped back their environmental commitment. Vanguard for instance left the Net Zero Asset Managers initiative in December 2022. Both firms also reported a substantial increase in rejections of ESG shareholders proposals. Source: "BlackRock and Vanguard were once ESG's biggest proponents–now they seem to be reversing course", Fortune, September 13th, 2023; Link.

Figure IA.2: Capital Reallocation versus Capital Utilization: Public Equity Investors



Each panel shows the three terms in the decomposition in equation (2) for a given investor group, across all plants in the EU over the period 2015-2022. The *Passive* category reflects investors whose investment style is labeled by Capital IQ as passive. The *Other Public Equity* category reflects public equity investors that are not labeled by Capital IQ as passive. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

of capital structure by including micro-data on firms' debt. We collect data on debt structure from Capital IQ for firms in our sample and divide financial liabilities into four groups: (i) equity (ii) bank debt (iii) bonds (iv) other debt.[63] We apply our decomposition to these four groups as shown in Figure IA.22 in the Internet Appendix. We see that over time there have been a de-leveraging of coal assets, with a rise in equity relative to debt. The decline is debt is entirely due to a fall in bond financing from capital markets. In fact, bank debt has been rising moderately during this time. This shift in debt structure is consistent with some of the findings of Walz [2022] and Luneva and Sarkisyan [2022].

Comparison with the U.S.: While the focus of this paper is on Europe, we provide

[63] The value of bank debt includes the value of revolving credit, term loans, lease liabilities, trust preferred securities, general and other borrowings. The value of bond debt includes the value of commercial paper, senior bonds and notes, and subordinated bonds and notes. The value of other debt includes the value of debt whose category is unknown, firms for which we do not have data on their debt structure, and adjustments to debt. The ownership percentage of each group is determined based on the group's value, with the value of equity determined by market prices for publicly listed firms and book equity for other firms.

a brief comparison with the U.S.[64] Overall, we find dynamics that are in line with the EU, but with significantly smaller magnitudes, as shown in Figure IA.24 and IA.25 in the Internet Appendix. Public equity ownership has declined by about 5pp, while ownership by private firms, governments, and cooperatives increased slightly. Our decomposition shows that there was no "exit" by public equity investors: capital utilization explains the decline. On the other hand, governments and cooperatives were also slower at scaling down their plants. The key difference with Europe is the absence of significant capital reallocation and private ownership has barely increased, in line with the evidence of Andonov and Rauh [2022]. Note that there is no obvious U.S. analog to prone-to-exit foreign state investors.

IA.2 Model extension: Permanent vs. Temporary Closure

We extend the model and assume that firms have four options for each of their units. In addition to keeping them on and selling them, they can now choose to either temporarily turn them off or permanently retire them. Temporarily turning off an unit, without retiring it, preserves the option value of turning it on later. If a firms does so, it must still pay an operating fixed cost $f > 0$.

- Keep on: $\pi^i - \epsilon - f$
- Sell: $P - \theta\epsilon$
- Temporarily off: $q(v(\pi^i) - \epsilon) - f$
- Retire: 0

[64] We collect data on the universe of coal power plants, as well as their CO2 emissions and owners from the EIA's Form EIA-860 and the EPA's Greenhouse Gas Reporting Program (GHGRP). We use the same procedure as in Europe to match firms to their investors using Capital IQ. For reference, Figure IA.23 in the Internet Appendix show that between 2014 and 2022 aggregate U.S. coal capacity and emissions have declined by 36% and 47%, respectively.

The payoff to temporarily turning off a unit can be interpreted in the following way. The benefit relative to permanently retiring the unit is the option value of turning it on later when its more profitable. We assume that the unit will be turned on again in the future with probability q (also capturing potential time discounting), in a state of the world in which its profitability is $v(\pi^i)$. We assume that this option value is always positive and increasing in the current profitability π^i.[65] On the other hand, there are two potential costs relative to retiring the unit: (i) an operating fixed cost $f > 0$, and (ii) the probability of future climate externalities $q\epsilon$. From the state perspective, we make the assumption that s is only foregone if the unit is retired, but not if it is temporarily turned off.

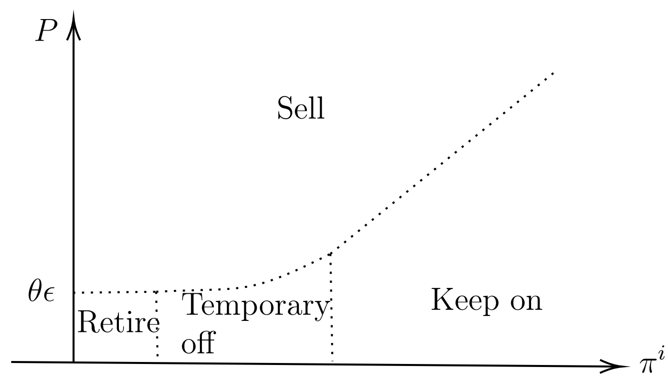
Figure IA.3 illustrates the capital choices in equilibrium with this additional option. Like in the data, we see that units are both temporarily turned off and retired in equilibrium. Intuitively, for the least profitable plants, the option value is not large enough to outweighs the pecuniary and non-pecuniary costs of temporarily turning a plant off. This implies that the state still has incentives to nationalize some units that the private sector would prefer to retire. A larger cost of climate externalities ϵ exacerbates these incentives.

IA.3 Model calibration and identification

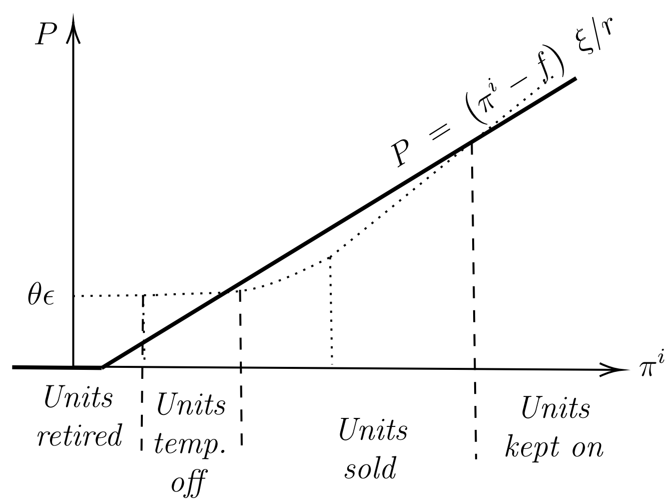
There are seven parameters to estimate:

1. The average profitability of units $\bar{\pi}$.
2. The cost of climate externalities ϵ.
3. The benefit of social factors s.
4. The mandate of public equity investors θ^P.
5. The mandate of national state investors θ^{NS}.

[65]Formally, assume that $v' > 0$, $\lim_{\pi^i \to -\infty} v(\pi^i) = 0$ and $\lim_{\pi^i \to +\infty} v(\pi^i)/\pi^i = 1^-$.



(a) Firm capital choice



(b) Equilibrium with financial frictions

Figure IA.3: Extension: Full retirement vs. Turning off

6. The mandate of foreign and local state investors θ^{FLS}.

7. The strength of financial frictions ξ/r (only the ratio is identified).

We use seven moments to identify these parameters:

1. The share of emissions retired by private firms.

2. The share of emissions kept by public equity investors.

3. The share of emissions retired by public equity investors.

4. The share of emissions kept by foreign/local state investors.

5. The share of emissions retired by foreign/local state investors.

6. The share of emissions kept by national state investors.

7. The share of emissions retired by national state investors.

For each investor group $g = \{\text{private, public equity, national state, foreign/local state}\}$, we denote the empirical moments as $\{R^g, K^g, S^g\}$. R^g is the share of initial emissions of group g that were retired over 2015-2020. K^g is the share of initial emissions of group g that were kept over 2015-2020. S^g is the share of initial emissions of group g that were kept over 2015-2020. The three shares adds to 100% for each group ($R^g + K^g + S^g = 1, \forall g$). We use seven of these for identifying the seven model parameters.

Moment 1: The share of emissions retired by private firms. The private firms' valuation of climate externalities is normalized to zero. In the model, the share of emissions retired is given by:

$$R^{private} = \mathbf{P}(\pi^i < 0) = \Phi(-\bar{\pi})$$

This moment identifies average profitability $-\bar{\pi}$.

Closed-form equation:

$$\bar{\pi} = -\Phi^{-1}(R^{private})$$

Moment 2: The share of emissions kept by public equity investors. In the model, the share of emissions kept is given by:

$$K^{public} = \mathbf{P}(\pi^i > \frac{1-\theta^{public}}{1-\xi/r}\epsilon) = \Phi(\bar{\pi} - \frac{1-\theta^{public}}{1-\xi/r}\epsilon)$$

Moment 3: The share of emissions retired by public equity investors. In the model, the share of emissions retired is given by:

$$R^{public} = \mathbf{P}(\pi^i < \frac{\theta^{public}}{\xi/r}\epsilon) = \Phi(\frac{\theta^{public}}{\xi/r}\epsilon - \bar{\pi})$$

Moment 4: The share of emissions kept by foreign and local state investors. In the model, the share of emissions kept is given by:

$$K^{FLS} = \mathbf{P}(\pi^i > \frac{1-\theta^{FLS}}{1-\xi/r}\epsilon) = \Phi(\bar{\pi} - \frac{1-\theta^{FLS}}{1-\xi/r}\epsilon)$$

Moment 5: The share of emissions retired by foreign and local state investors. In the model, the share of emissions retired is given by:

$$R^{FLS} = \mathbf{P}(\pi^i < \frac{\theta^{FLS}}{\xi/r}\epsilon) = \Phi(\frac{\theta^{FLS}}{\xi/r}\epsilon - \bar{\pi})$$

Given that $\bar{\pi}$ is already identified, these last four moments jointly identify the climate externalities ϵ, the mandates θ^{Public}, θ^{FLS}, and the strength of financial frictions ξ/r.

Closed-form equations:

$$\theta^{FLS} = \frac{1 - \frac{\bar{\pi}-\Phi^{-1}(K^{Public})}{\bar{\pi}-\Phi^{-1}(K^{FLS})}}{\frac{\bar{\pi}+\Phi^{-1}(R^{Public})}{\bar{\pi}+\Phi^{-1}(R^{FLS})} - \frac{\bar{\pi}-\Phi^{-1}(K^{Public})}{\bar{\pi}-\Phi^{-1}(K^{FLS})}}$$

$$\theta^{Public} = \theta^{FLS}\frac{\bar{\pi}+\Phi^{-1}(R^{Public})}{\bar{\pi}+\Phi^{-1}(R^{FLS})}$$

$$\epsilon = 1/(\frac{1-\theta^{Public}}{\bar{\pi}-\Phi^{-1}(K^{Public})} + \frac{\theta^{Public}}{\bar{\pi}+\Phi^{-1}(R^{Public})})$$

$$\xi/r = \frac{\epsilon\theta^{Public}}{\bar{\pi}+\Phi^{-1}(R^{Public})}$$

Moment 6: The share of emissions kept by national state investors. In the model, the share of emissions kept is given by:

$$K^{NS} = \mathbf{P}(\pi^i > \frac{1-\theta^{NS}}{1-\xi/r}(\epsilon - s)) = \Phi(\bar{\pi} - \frac{1-\theta^{NS}}{1-\xi/r}(\epsilon - s))$$

Moment 7: The share of emissions retired by national state investors. In the model, the share of emissions retired is given by:

$$R^{NS} = \mathbf{P}(\pi^i < \frac{\theta^{NS}}{\xi/r}(\epsilon - s)) = \Phi(\frac{\theta^{NS}}{\xi/r}(\epsilon - s) - \bar{\pi})$$

Given that $\bar{\pi}$, ϵ and ξ/r are already identified, these two moments jointly identifies the mandate of national state θ^{NS} and the benefit of social factors s.

Closed-form equation:

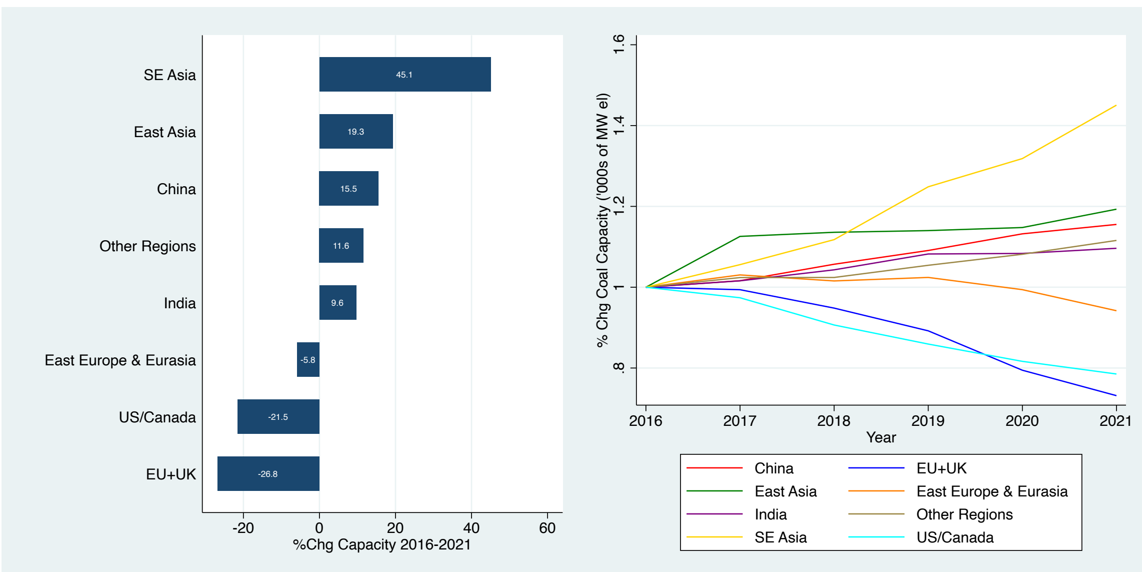
$$\theta^{NS} = 1/(1 + \frac{\bar{\pi}-\Phi^{-1}(K^{NS})}{\bar{\pi}+\Phi^{-1}(R^{NS})}\frac{1-\xi/r}{\xi/r})$$

$$s = \epsilon - (\bar{\pi}+\Phi^{-1}(R^{NS}))\frac{\xi/r}{\theta^{NS}}$$

In the case in which national state investors do not sell any units, these equations are still valid but only provide a lower bound for θ^{NS}, equal to ξ/r.

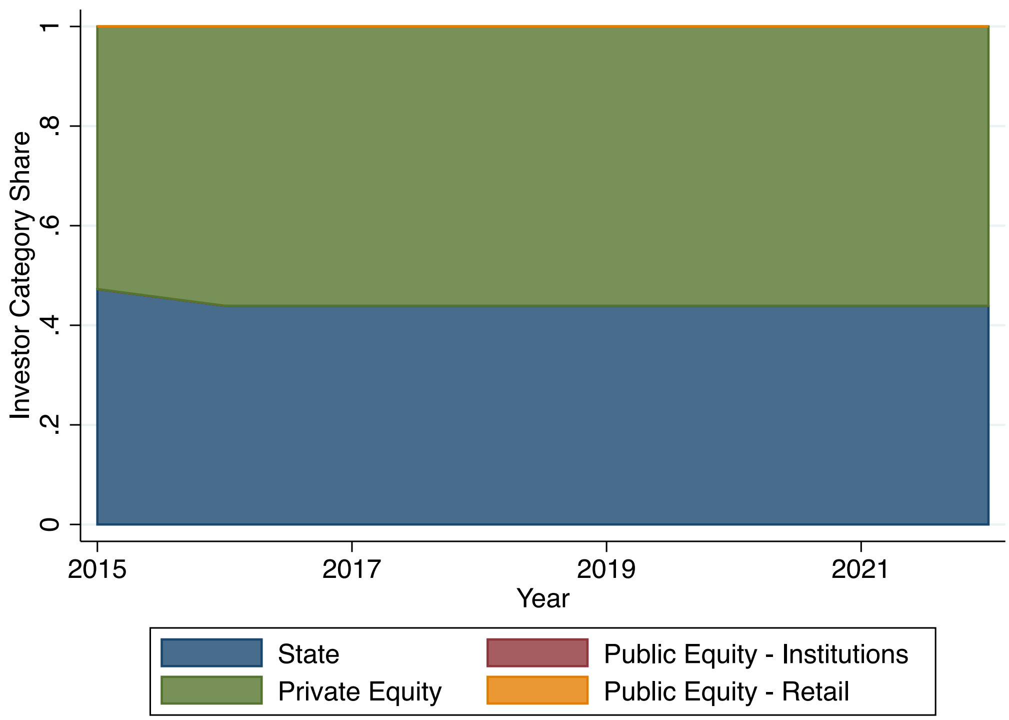
IA.4 Additional Figures and Tables

Figure IA.4: Change in Coal Capacity across Regions: 2016-2021



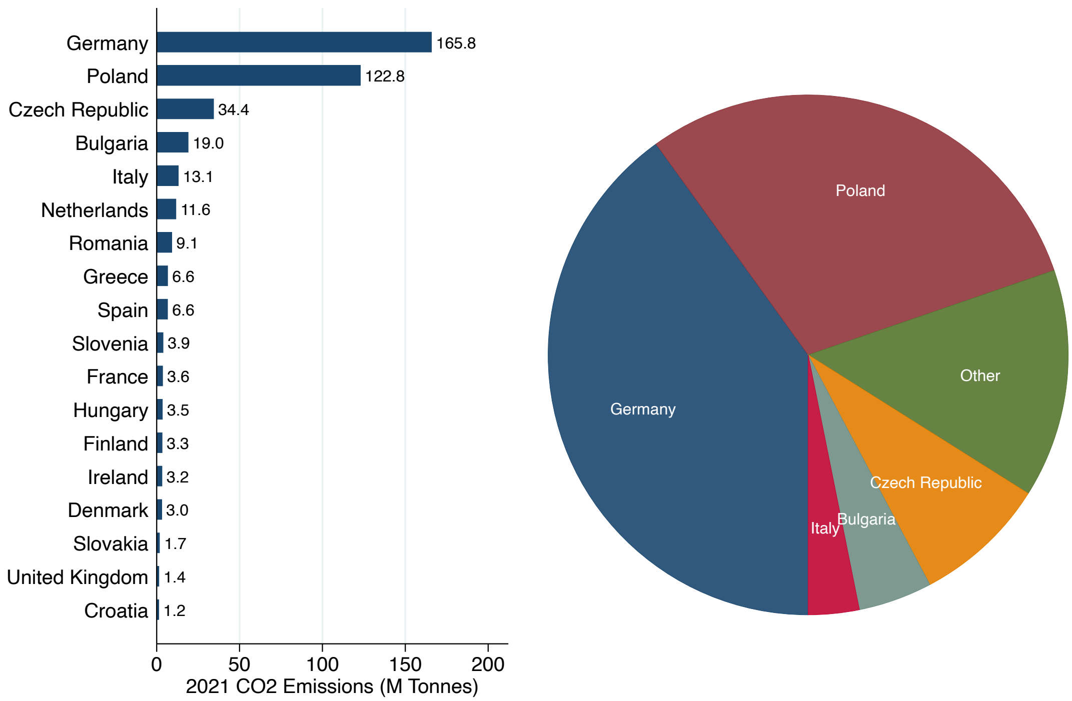
This figure shows the change in coal capacity in different regions of the world. The data comes the Global Energy Monitor coal power plant tracker.

Figure IA.5: Ownership of Coal Capacity Outside of the EU, 2015-2022



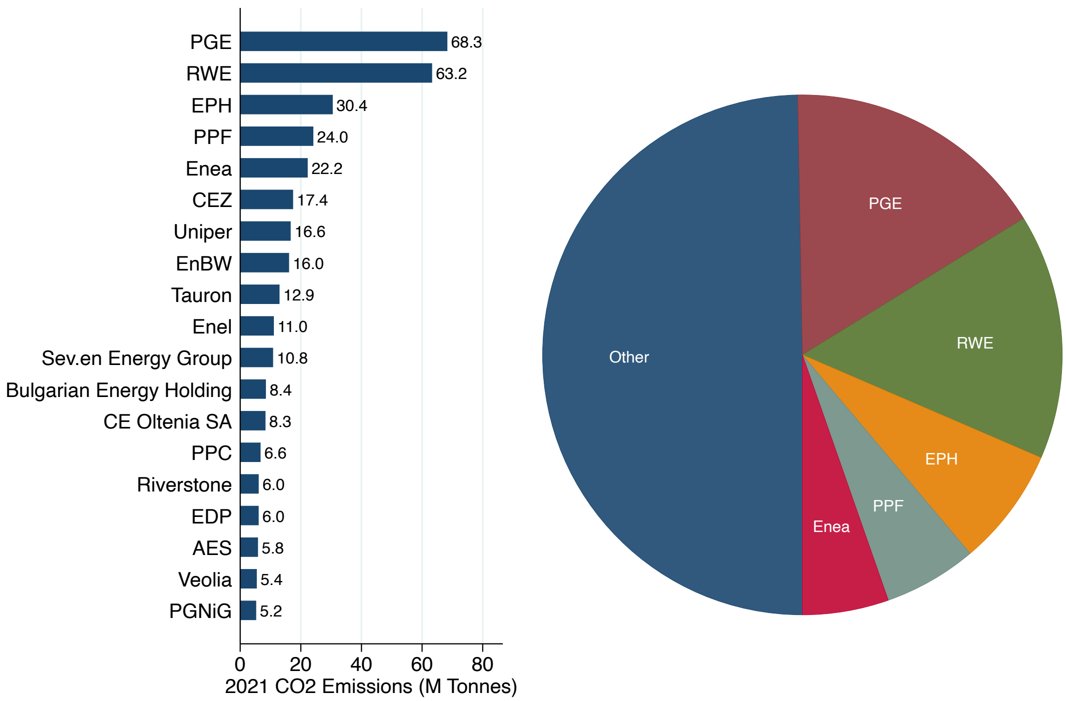
This figure shows the share of coal capacity from plants outside the EU present in the BFF data owned by the different investor categories. These plants are mainly located in Turkey, with plants also in Bosnia & Herzegovina, Kosovo, Montenegro, North Macedonia, Serbia.

Figure IA.6: Country-Level CO2 Emissions from Coal Plants, 2021



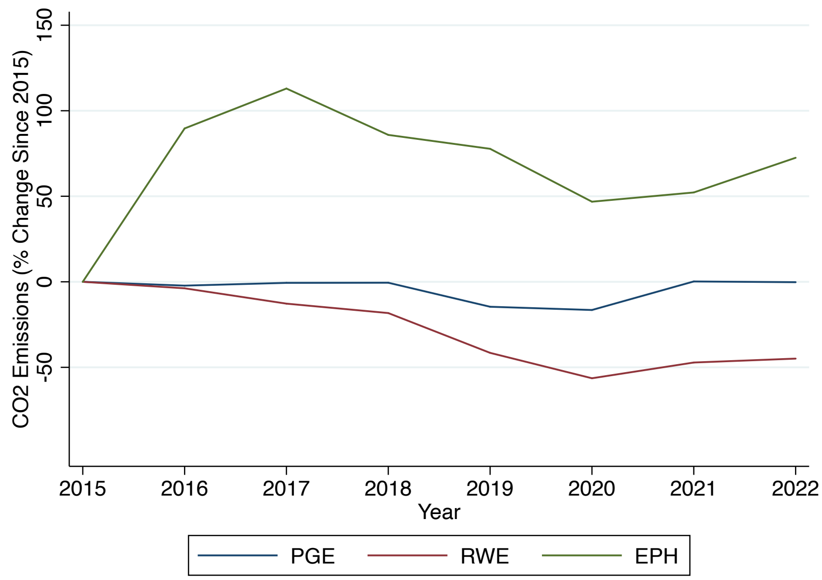
The bar chart on the left shows CO2 emissions in 2021 at the country level from the BFF data, for countries in the EU and UK for which open coal plants emitted more than 1 Million Tonnes of CO2. The pie chart on the right shows the share of CO2 emissions from coal plants for the top 5 highest-emitting countries. An "Other" category is also included that represents the remaining share of CO2 emissions not covered by the top 5. Note the "Other" category may include countries that are not present in the bar chart on the left.

Figure IA.7: Firm-Level CO2 Emissions from Coal Plants, 2021



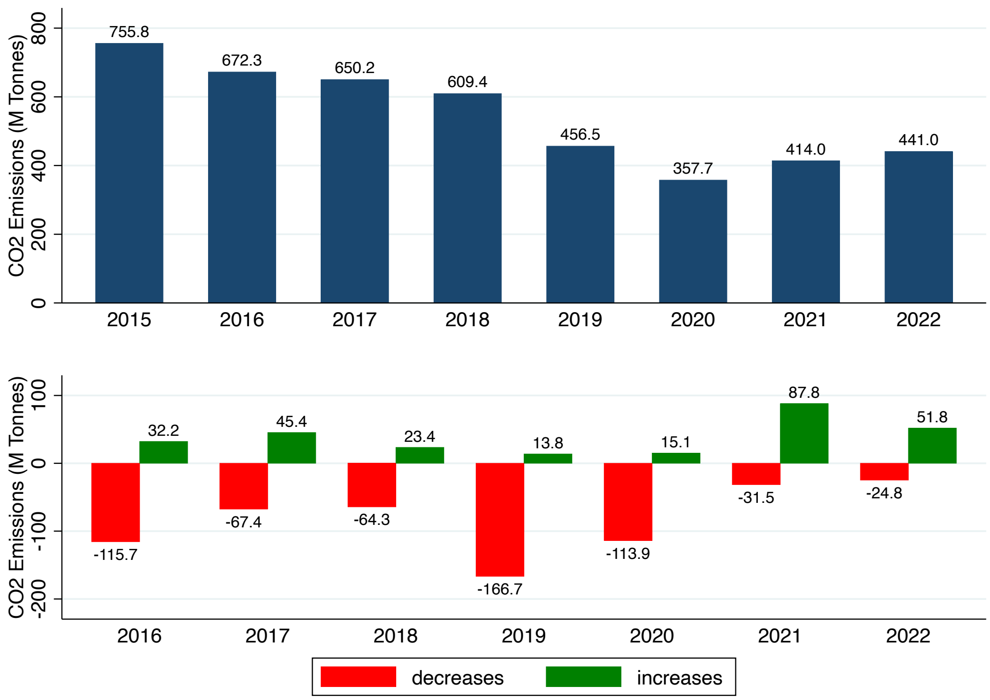
The bar chart on the left shows CO2 emissions in 2021 at the firm level from the BFF data, for the top 19 highest-emitting firms who owned open coal plants in the EU. The pie chart on the right shows the shares of CO2 emissions attributable to the top 5 highest-emitting firms. An "Other" category is also included that represents the remaining share of CO2 emissions not covered by the top 5. Note the "Other" category may include firms that are not present in the bar chart on the left.

Figure IA.8: Dynamics of CO2 Emissions by PGE, RWE, and EPH, 2015-2022



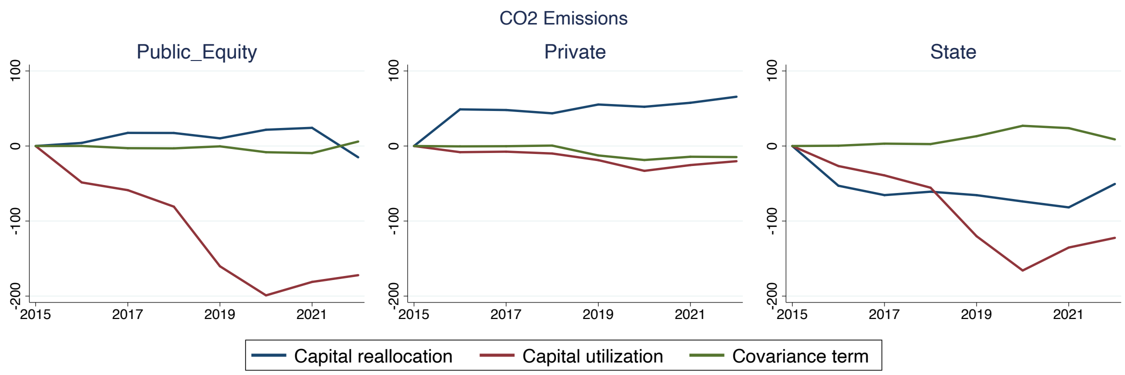
This figure shows the annual percentage change in CO2 emissions relative to 2015 produced by plants owned by PGE, RWE, and EPH. Coal plant data are from Beyond Fossil Fuels.

Figure IA.9: Aggregate Coal Emissions in the EU



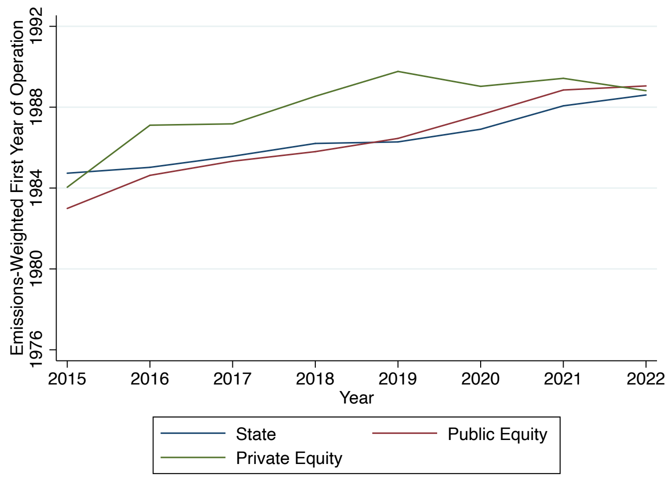
The top panel shows aggregate CO2 emissions across all open coal plants in the EU and UK, from 2015 to 2022. The bottom panel shows changes in CO2 emissions across coal units that exhibited increases in emissions and units that exhibited decreases in emissions. Aggregate CO2 emissions for year t is equivalent to aggregate CO2 emissions for year $t-1$, adding any emission increases by units in year t and subtracting any emission decreases by units in year t. Coal plant data are from Beyond Fossil Fuels.

Figure IA.10: Capital Reallocation versus Capital Utilization: Levels of Emissions



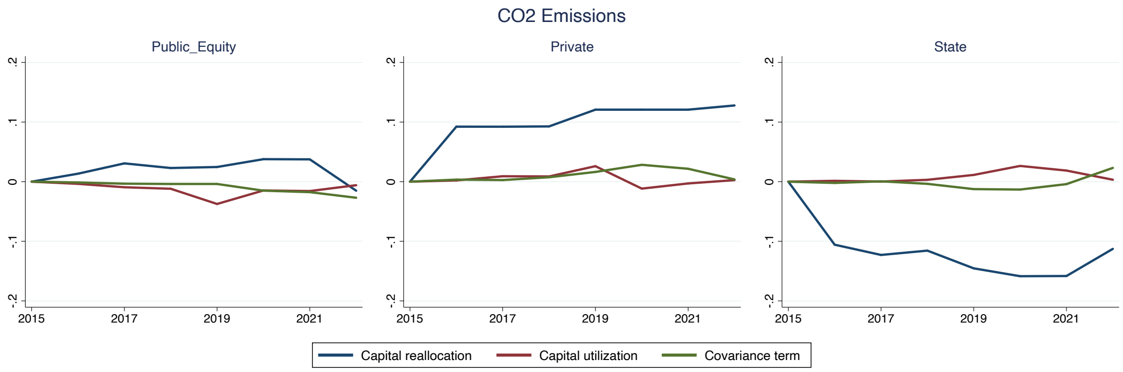
Each panel shows the three terms in the decomposition in equation (2) for a given investor group, across all plants in the EU, using levels of emissions to measure plant scale instead of emissions as a proportion of aggregate emissions, over the period 2015-2022. The *Public Equity* category reflects retail or (non-state) institutional investors in publicly traded companies. The *Private* category reflects non-state owners of private companies. The *State* category reflects state-owned shares in both public and private companies. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.11: Emissions-Weighted First Year of Operation by Investor Group



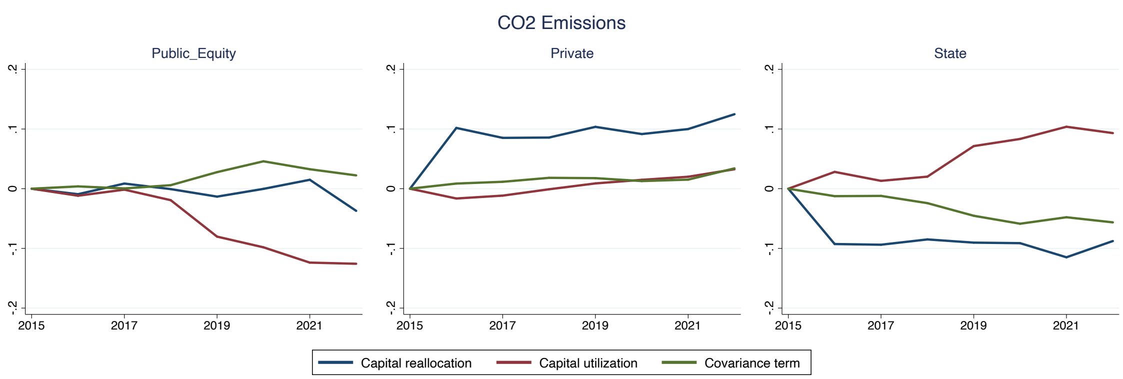
The *Public Equity* category reflects retail or (non-state) institutional investors in publicly traded companies. The *Private* category reflects non-state owners of private companies. The *State* category reflects state-owned shares in both public and private companies. For a investor group j, we define Emissions-Weighted First Year of Operation$_{j,t}$ $= \sum_i \frac{CO2_{ij,t}}{\sum_{i'} CO2_{i'j,t}}$First Year of Operation$_{i,t}$, where the i subscript indexes electricity generation units. $CO2_{ij,t}$ is the level of $CO2$ emissions attributable to investor group j for unit i.

Figure IA.12: Decomposition: Young Units



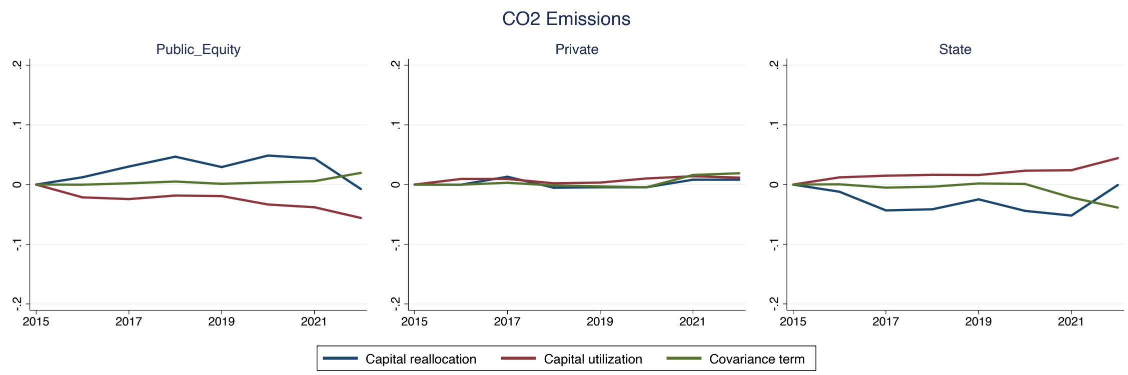
Operational coal units are divided into three age groups (*Young, Middle-Aged, and Old)* based on emissions-weighted terciles, so that each group captures approximately one-third of aggregate CO2 emissions. Operational coal units are classified into an age category based on their age and CO2 emissions as of 2015. CO2 emissions are available at the plant level, but allocated to units based on the coal capacity of each unit. Each panel in the figure shows the three terms in the decomposition in equation (2) for a given investor group, using the coal unit as the level of observation across units in the lowest age tercile over the period 2015-2022. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.13: Decomposition: Middle-Aged Units



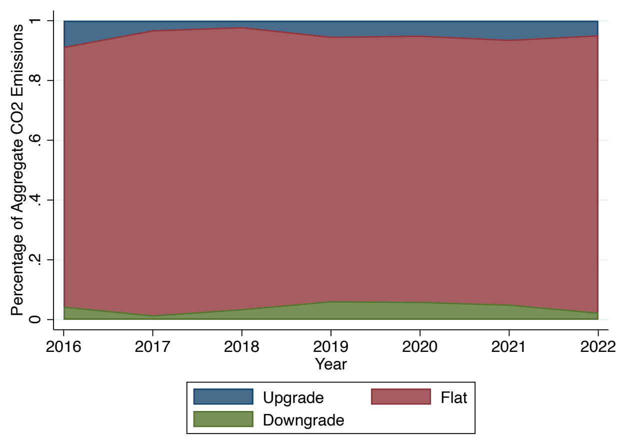
Operational coal units are divided into three age groups (*Young, Middle-Aged, and Old)* based on emissions-weighted terciles, so that each group captures approximately one-third of aggregate CO2 emissions. Operational coal units are classified into an age category based on their age and CO2 emissions as of 2015. CO2 emissions are available at the plant level, but allocated to units based on the coal capacity of each unit. Each panel in the figure shows the three terms in the decomposition in equation (2) for a given investor group, using the coal unit as the level of observation across units in the middle age tercile over the period 2015-2022. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.14: Decomposition: Old Units



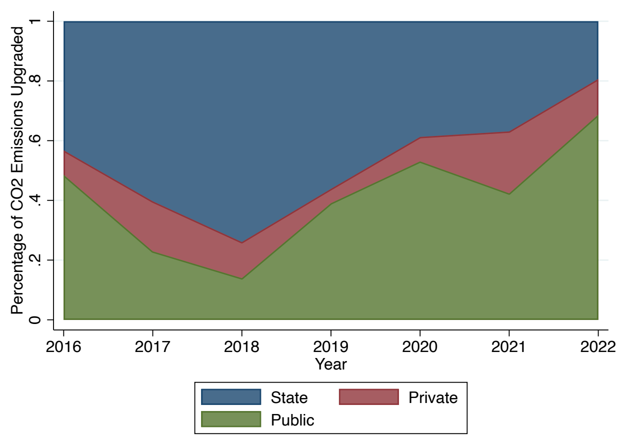
Operational coal units are divided into three age groups (*Young, Middle-Aged, and Old)* based on emissions-weighted terciles, so that each group captures approximately one-third of aggregate CO2 emissions. Operational coal units are classified into an age category based on their age and CO2 emissions as of 2015. CO2 emissions are available at the plant level, but allocated to units based on the coal capacity of each unit. Each panel in the figure shows the three terms in the decomposition in equation (2) for a given investor group, using the coal unit as the level of observation across units in the highest age tercile over the period 2015-2022. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.15: Share of technological upgrades in plant efficiency



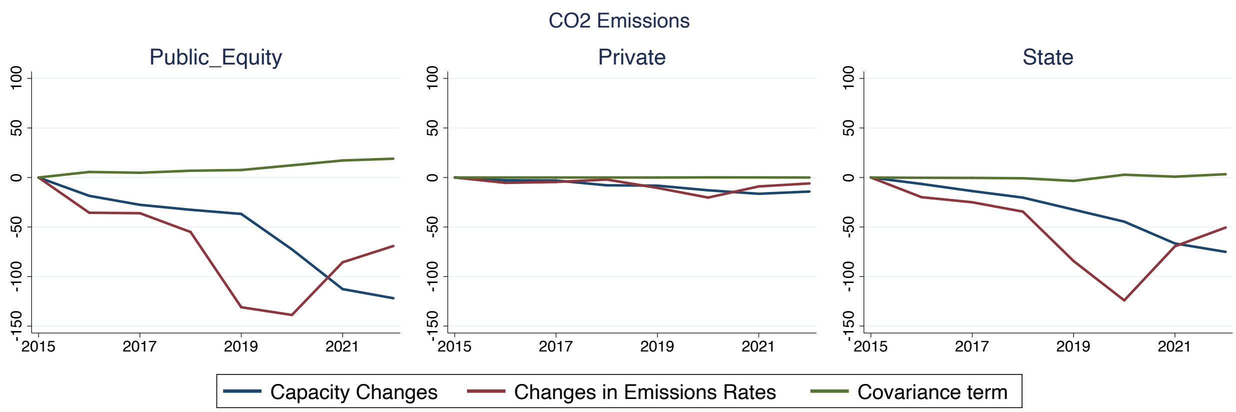
This figure shows the annual percentage of CO2 emissions, categorizing plants by whether they experienced technological upgrades, downgrades, or neither. *Upgrade* refers to plants whose emission intensity had increased by more than 10% since the previous year. *Downgrade* refer to plants whose emissions intensity has decreased by more than 10%. *Flat* refers to plants whose emissions intensity stayed within ± 10%. Emissions intensity (Tonnes/MWh) for a plant is calculated as annual CO2 emissions divided by the annual electricity output. Electricity output data is sourced from the European Network of Transmission System Operators for Electricity (ENTSO-e) Transparency Platform. Data is submitted to the ENTSO-e by data providers such as TSOs, who are legally obligated to provide such data in the EU."Aggregate CO2 Emissions" refers to the total CO2 emissions of plants with electricity data available in the ENTSO-e platform. Approximately 80% of CO2 emissions is covered. Only generators above a certain size threshold are included in the ENTSO-e data.

Figure IA.16: Technological upgrades in plant efficiency by investor groups



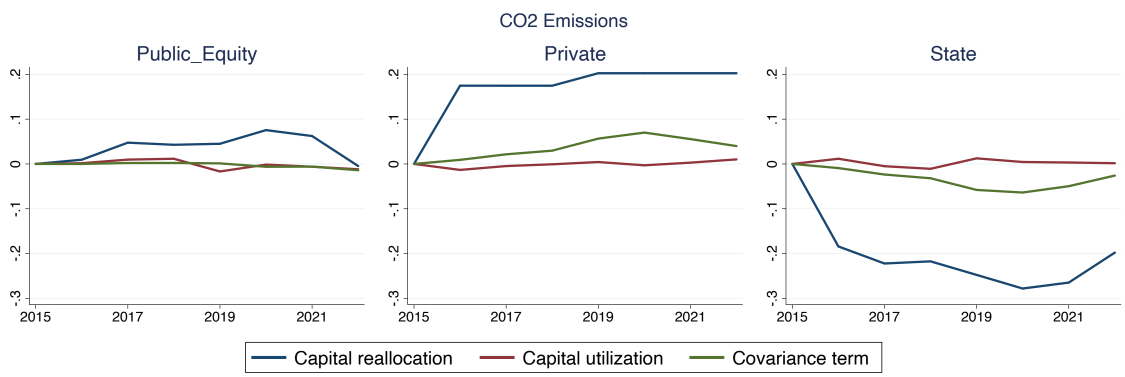
This figure shows the percentage of CO2 emissions from upgraded plants attributable to each investor group. Upgraded plants experience a decrease of more than 10% in CO2 emissions intensity from the previous year. Electricity output data is sourced from the European Network of Transmission System Operators for Electricity (ENTSO-e) Transparency Platform. Data is submitted to the ENTSO-e by data providers such as TSOs, who are legally obligated to provide such data in the EU.

Figure IA.17: Decomposing Capital Utilization



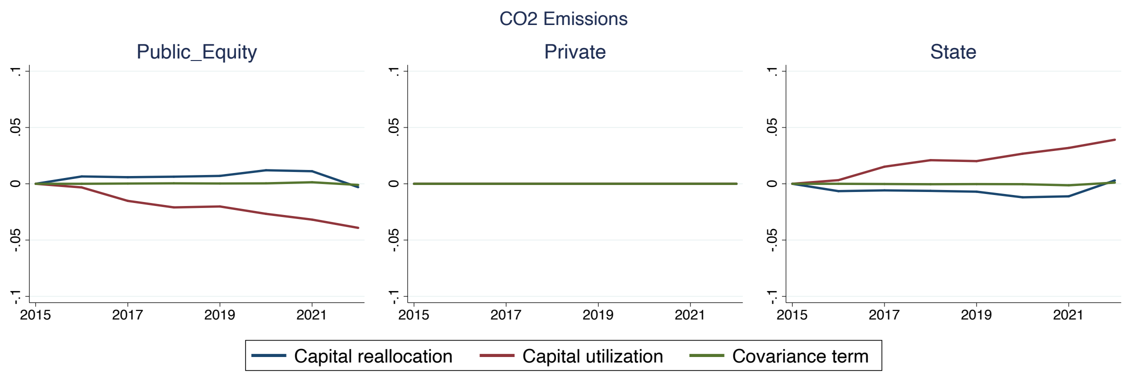
Each panel shows the three terms in the decomposition in equation (4) for a given investor group, across all plants in the EU over the period 2015-2022. The *Public Equity* category reflects retail or (non-state) institutional investors in publicly traded companies. The *Private* category reflects non-state owners of private companies. The *State* category reflects state-owned shares in both public and private companies. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.18: Capital Reallocation versus Capital Utilization: Germany



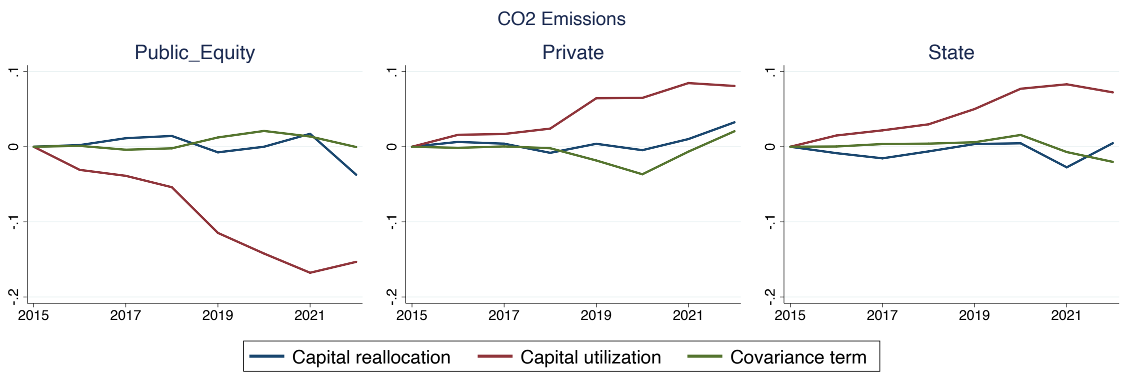
Each panel shows the three terms in the decomposition in equation (2) for a given investor group, across all plants in Germany over the period 2015-2022. The *Public Equity* category reflects retail or (non-state) institutional investors in publicly traded companies. The *Private* category reflects non-state owners of private companies. The *State* category reflects state-owned shares in both public and private companies. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.19: Capital Reallocation versus Capital Utilization: Poland



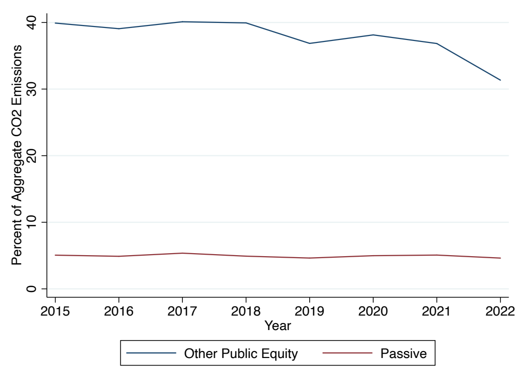
Each panel shows the three terms in the decomposition in equation (2) for a given investor group, across all plants in Poland over the period 2015-2022. The *Public Equity* category reflects retail or (non-state) institutional investors in publicly traded companies. The *Private* category reflects non-state owners of private companies. The *State* category reflects state-owned shares in both public and private companies. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.20: Capital Reallocation versus Capital Utilization: EU excluding Germany and Poland



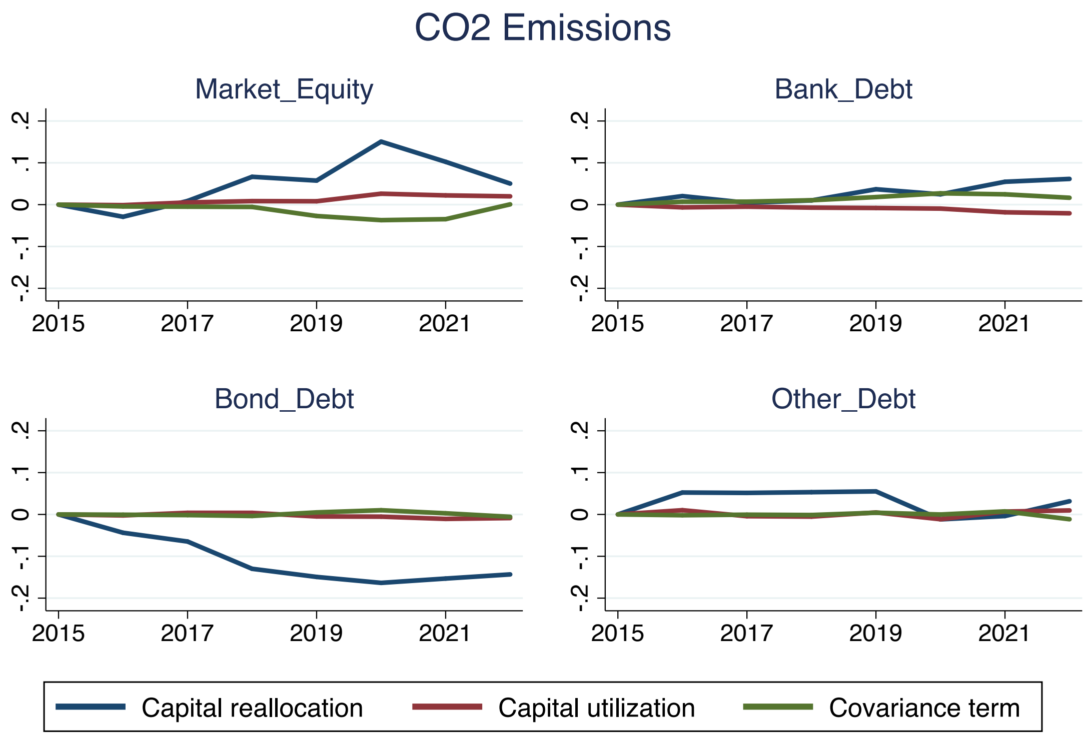
Each panel shows the three terms in the decomposition in equation (2) for a given investor group, across all plants in the EU, excluding Germany and Poland over the period 2015-2022. The *Public Equity* category reflects retail or (non-state) institutional investors in publicly traded companies. The *Private* category reflects non-state owners of private companies. The *State* category reflects state-owned shares in both public and private companies. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.21: CO2 Emissions (EU + UK) by Institutional Investor Categories



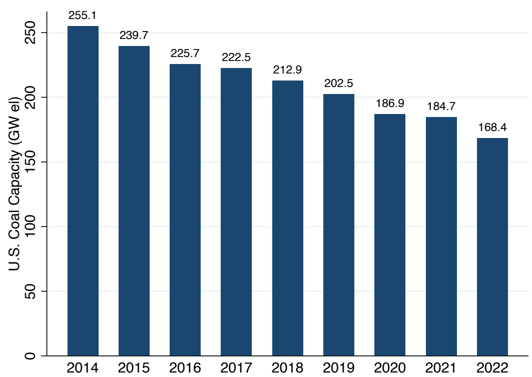
This figure shows the share of annual aggregate CO2 emissions in the EU owned by passive investors and other public equity investors. The *Passive* category reflects investors whose investment style is labeled by Capital IQ as passive. The *Other Public Equity* category reflects public equity investors that are not labeled by Capital IQ as passive. Coal plant data are from Beyond Fossil Fuels. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research.

Figure IA.22: Decomposition: Bank and Bond Debt

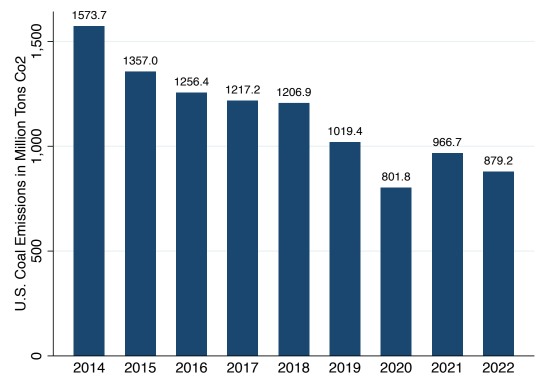


Each panel shows the three terms in the decomposition in equation (2) for a given investor group, across all plants in the EU over the period 2015-2022. The *Market Equity* category reflects equity investors. The *Bank Debt* category reflects debt holders that are banks. The *Bond Debt* category reflects bond investors. The *Other Debt* category reflects the portion of firm debt that is unknown, firms' whose debt structure is not observed in the data, and adjustments to debt. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.23: Aggregate Coal Power Generation in the U.S.



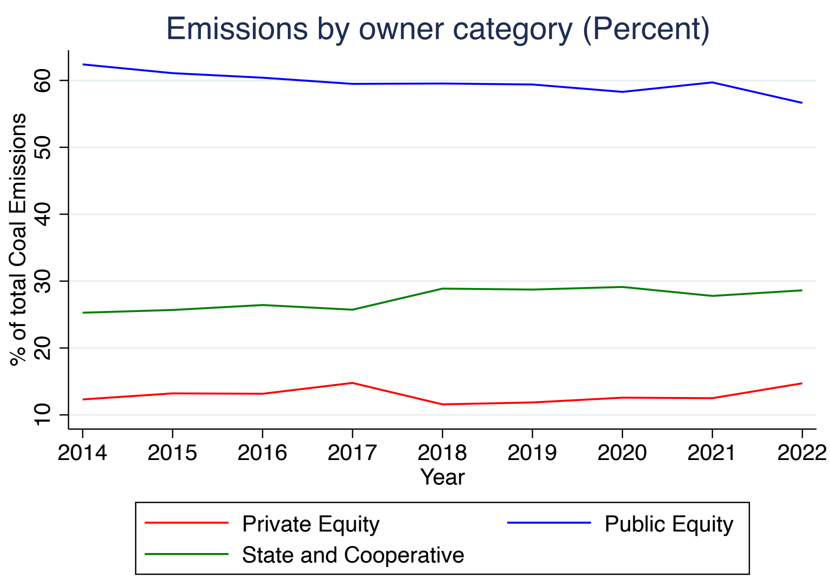
(a) Generating capacity



(b) CO2 emissions

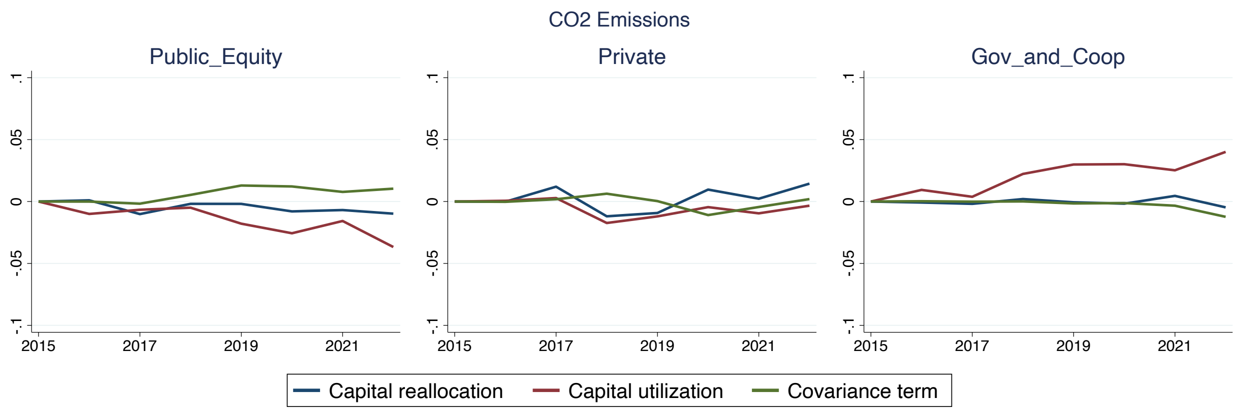
Coal plant data are from the EIA. Data on plant-level CO2 emissions are from the EPA.

Figure IA.24: Ownership of CO2 Emissions in the US, 2014-2022



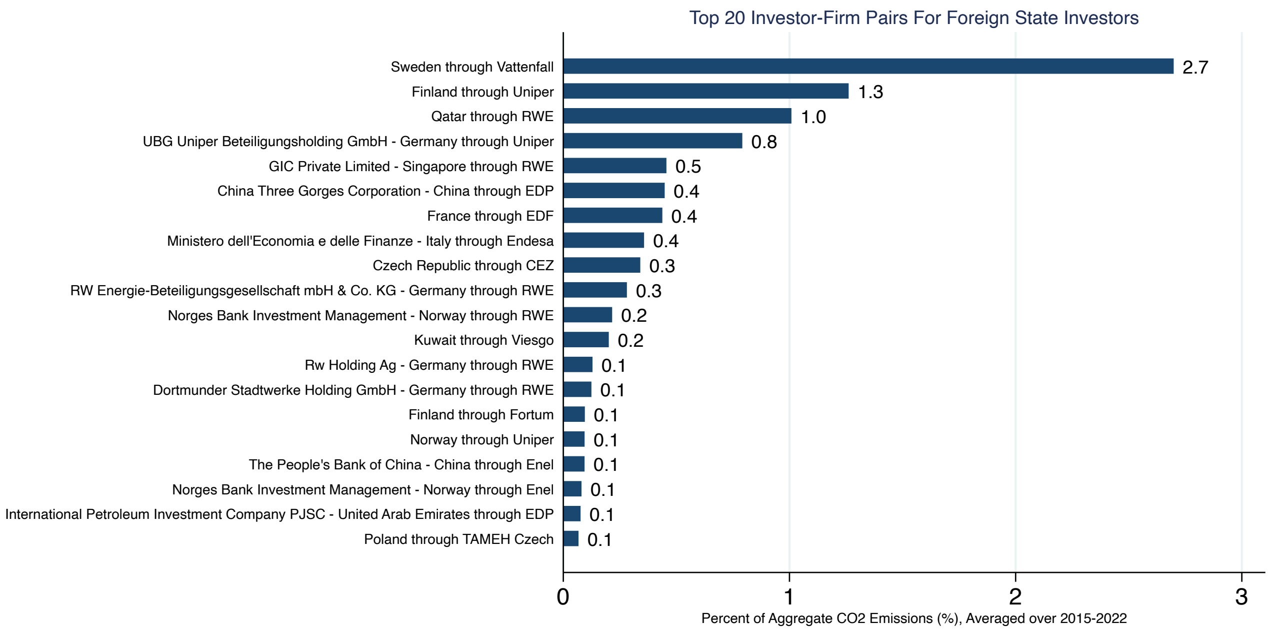
This figure shows the share of annual aggregate CO2 emissions from coal plants in the US owned by each of three investor categories. Coal plant data are from the EIA. Data on plant-level CO2 emissions are from the EPA.

Figure IA.25: Capital Reallocation versus Capital Utilization: U.S.



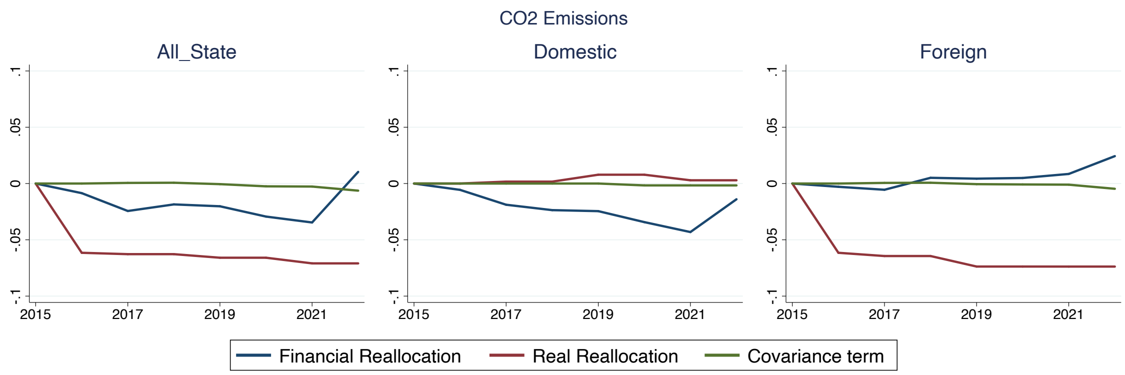
Each panel shows the three terms in the decomposition in equation (2) for a given investor group, across all plants in the United States over the period 2015-2022. Coal plant data are from the EIA. Data on plant-level CO2 emissions are from the EPA.

Figure IA.26: Top Foreign State Investors



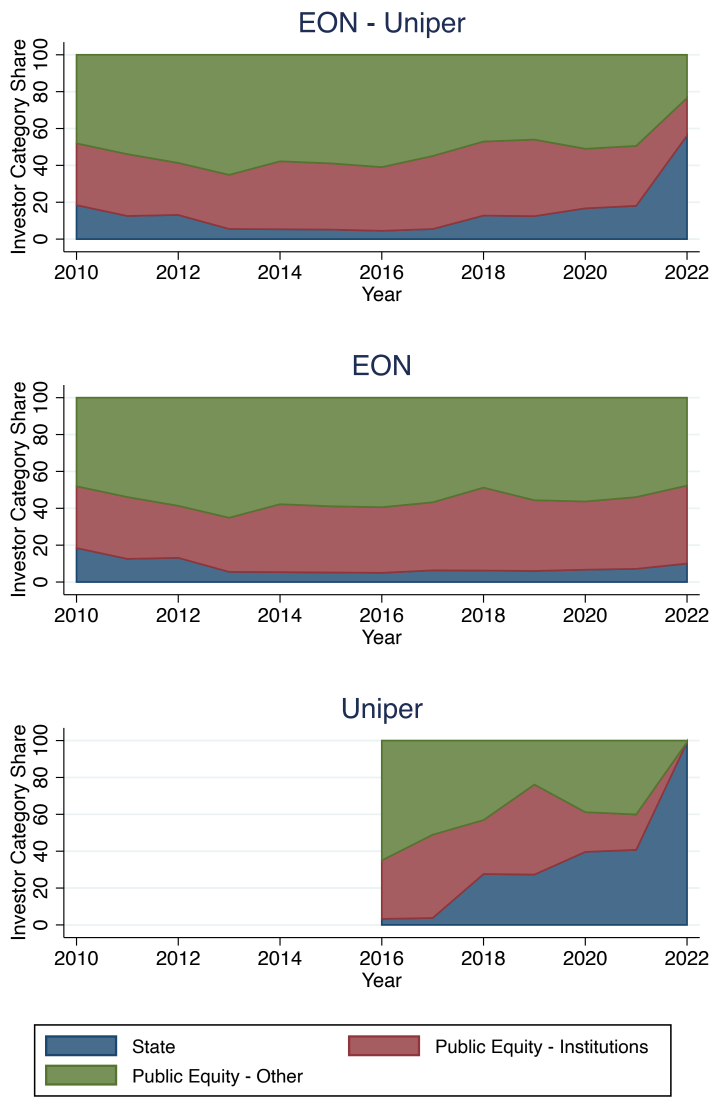
This figure shows the top 20 investor-firm pairs where the investor is a state entity who owned coal plants in a foreign country through the given firm. For example, the top entry reflects the fact that Sweden owns 100% of Vattenfall, who owned coal plants in Germany and Netherlands. The x-axis shows the percent of aggregate CO2 emissions owned in foreign countries by the investor through the particular firm, averaged over the 2015-2022 period. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.27: Financial Reallocation versus Real Reallocation: State Investors



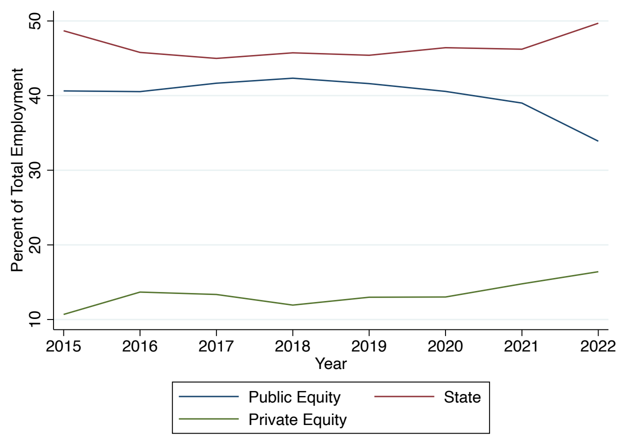
Each panel shows the three terms in the decomposition in equation (3) for a given investor group, across all plants in the EU over the period 2015-2022. The *All State* category reflects all state investors. The *Domestic* category reflects only domestic state investors. A state investor in a plant is considered domestic if it is affiliated with a local or state government that is located in the same country as the plant it owns. The *Foreign* category reflects only foreign state investors. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.28: Ownership dynamics: the E.ON -Uniper Asset Split



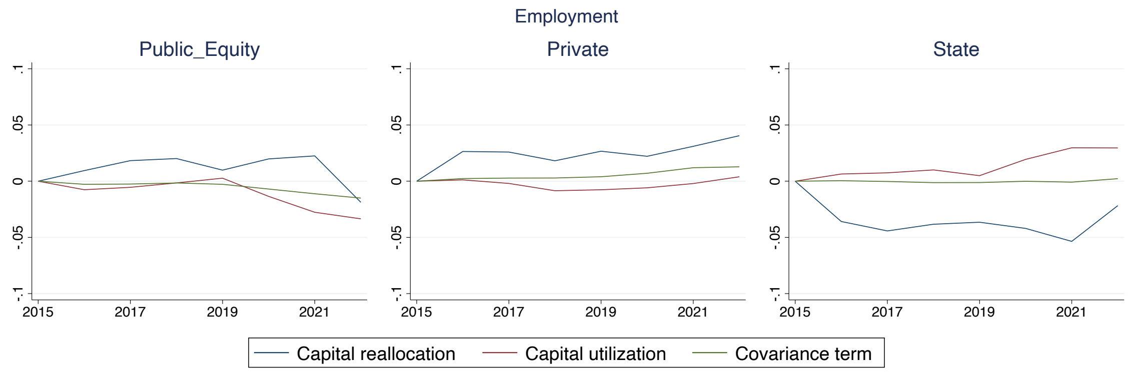
The top panel *EON-Uniper* plots the shares by investor group for E.ON through 2015. After and including 2016, the top panel represents the weighted-average of shares held by investor groups for Uniper and E.ON, with each company's share weighted by its respective market capitalization. The middle panel *EON* plots the shares by investor group for E.ON, and the bottom panel *Uniper* plots the shares by investor group for Uniper. Uniper was spun off from E.ON in 2016. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research.

Figure IA.29: Ownership of Coal Plant Employment in the EU, 2015-2022



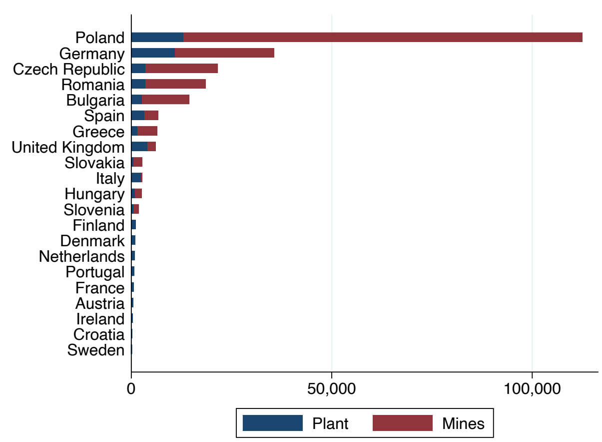
This figure shows the share of employment from coal plants in the EU attributable to public equity investors, private equity investors, and state investors. The number of jobs for each coal generation unit is computed by multiplying the open coal capacity of the unit times a country-specific coefficient that estimates Jobs per MW. Country-specific coefficients of Jobs per MW are sourced from Alves Dias et al. [2018], Annex 6. Belgium is not represented in Alves Dias et al. [2018]; Belgium's country-specific coefficient is imputed with 0.49, which is the simple average of the coefficients for other countries. Coal plant data are from Beyond Fossil Fuels. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research..

Figure IA.30: Capital Reallocation versus Capital Utilization: Employment



Each panel shows the three terms in the decomposition in equation (2) for a given investor group, across all plants in the EU over the period 2015-2022. The *Public Equity* category reflects retail or (non-state) institutional investors in publicly traded companies. The *Private* category reflects non-state owners of private companies. The *State* category reflects state-owned shares in both public and private companies. The number of jobs for each coal generation unit is computed by multiplying the open coal capacity of the unit times a country-specific coefficient that estimates Jobs per MW. Country-specific coefficients of Jobs per MW are sourced from Alves Dias et al. [2018], Annex 6. Belgium is not represented in Alves Dias et al. [2018]; Belgium's country-specific coefficient is imputed with 0.49, which is the simple average of the coefficients for other countries. Firm shareholder information and classifications are determined using a combination of data from Capital IQ and manual research. Coal plant data are from Beyond Fossil Fuels.

Figure IA.31: Coal Employment by Country (2016)



This figure shows employment attributable to coal plants and coal mines for each country in the EU. From Alves Dias et al. [2018], Table 3.

Table IA.1: Top 10 Largest Coal Power Producers in Selected Regions, 2021

	USA	EU/UK	China	India
Av. State Investor Share (%)	10.6	30.8	84.6	45.2
State-owned enterprises (%)	10	0	80	40
Capacity (MW'000)	108.4	84.9	309.8	122.1

Average State Investor Share refers to the average percentage of equity held in the top 10 firms of each region by state institutions. For USA, China and India this percentage only refers to the percentage held by domestic institutions, for reasons of data limitations. For the EU/UK, any shareholder government is considered. A company is classified as a *state-owned enterprise* if 100% of the equity is held by a government institution. The data comes the Global Energy Monitor coal power plant tracker.

Table IA.2: Ownership and Capacity for Largest Coal Power-Producing Energy Firms for Selected Regions, 2021

Name	Type	% State Investor	Capacity (MW'000)
China			
China Huaneng	State-owned	100	73.0
National Energy Investment Group	State-owned	100	55.6
China Huadian	State-owned	100	50.3
China Datang	State-owned	100	41.1
State Power Investment Corporation	State-owned	100	32.0
China Resources	State-owned	100	17.8
Shandong Weiqiao Group	Private	0	17.5
Henan Investment Group	State-owned	100	8.2
Beijing Energy Group	Publicly traded	45.59	7.2
Datong Coal Mining Group	State-owned	100	7.2
United States			
Duke Energy	Publicly traded	0	18.5
NRG Energy	Publicly traded	0	14.4
Southern Company	Publicly traded	0	13.6
American Electric Power	Publicly traded	0	13.6
Berkshire Hathaway	Publicly traded	0	11.0
Vistra	Publicly traded	6.23	8.4
Tennessee Valley Authority	State-owned	100	8.1
Xcel Energy	Publicly traded	0	7.9
Evergy	Publicly traded	0	6.5
DTE Energy	Publicly traded	0	6.4
India			
NTPC	Publicly traded	51.12	52.7
Adani Group	Private	0	11.8
MAHAGENCO	State-owned	100	9.8
Vedanta Resources	Private	0	8.3
Rajasthan RV Utpadan Nigam	State-owned	100	7.8
Damodar Valley Corporation	State-owned	100	7.1
Jindal Group	Publicly traded	0.80	6.4
Reliance Group	Publicly traded	0.60	6.3
Tata Group	Publicly traded	0	6.3
UPRVUNL	State-owned	100	5.5
EU/UK			
PGE	Publicly traded	57.52	14.0
RWE	Publicly traded	3.03	13.5
EPH	Private	0	11.4
PPF	Private	0	8.3
Uniper	Publicly traded	40.73	7.7
EnBW	Publicly traded	96.48	7.5
Enea	Publicly traded	51.50	5.8
Enel	Publicly traded	25.59	5.8
Tauron	Publicly traded	33.51	5.4
Steag	Private	0	5.4

The variable *% State Investor* refers to the share of equity held by a government institution. For the USA, China and India, this share only refers to domestic institutions, for reasons of data limitations. A company is classified as *state-owned* if 100% of the equity is held by a government institution. The data comes the Global Energy Monitor coal power plant tracker.

	Parameter	Moment	Estimate
1	Average profitability of units $\bar{\pi}$	Share of emissions retired by private firms	0.83
2	Cost of climate externalities ϵ	Share of emissions retired by public equity investors	1.14
3	Benefit of social externalities s	Share of emissions kept by national state investors	0.90
4	Mandate of public equity investors θ^{P}	Share of emissions kept by public equity investors	0.47
5	Mandate of national state investors θ^{NS}	Share of emissions retired by national state investors	0.40
6	Mandate of foreign/local state investors θ^{FLS}	Share of emissions kept by foreign/local state investors	0.30
7	Financial frictions ξ/r	Share of emissions retired by foreign/local state investors	0.48

Table IA.3: Model calibration: Robustness

Parameter	Estimate - up to 2020	Estimate - up to 2022
Average profitability of units $\bar{\pi}$	0.18	0.62
Cost of climate externalities ϵ	0.47	0.78
Financial frictions ξ/r	0.81	0.79
Mandate of public equity investors θ^{P}	0.81	0.79
Mandate of foreign state investors θ^{FLS}	0.42	0.56
Benefit of social factors s		
Poland	0.95	1.43
Germany	0.00	0.38
Other EU	0.21	0.37
Mandate of domestic state investors θ^{DS}		
Poland	0.82	0.79
Germany	0.67	0.59
Other EU	0.87	0.74

Table IA.4: Model calibration: Extension