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Abstract

Climate policies to keep global warming below 2°C might render some of the world's fossil fuels and related infrastructure worthless prior to the end of their economic life time. Therefore, some energy-sector assets are at risk of becoming stranded. This paper investigates whether and how investors price in this risk of asset stranding. We exploit the gradual development of a German climate policy proposal aimed at reducing electricity production from coal and analyze its effect on the valuation of energy utilities. We find that investors take stranded asset risk into consideration, but that they also expect a financial compensation for their stranded assets.

JEL-Codes: Q350, Q380, G140.

Keywords: stranded assets, climate policy, expectations, utilities, event study.

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1 Introduction

As early as 2012, global financial services companies drew attention to the risk of coal investments becoming stranded as a consequence of the 2°C "carbon budget."[1] This carbon budget specifies the maximal amount of cumulative carbon emissions that can be emitted without surpassing a 2°C temperature increase above the preindustrial levels (Meinshausen et al., 2009; Allen et al., 2009). Therefore, climate policies might render fossil-fuel assets worthless prior to the end of their economic life time. We study whether the current market valuation of companies owning fossil fuel assets reflect this risk of stranding assets.[2] A failure to price in this risk can lead to costly consequences for the whole economy. First, the resulting misallocation of capital due to delayed divestment could render the transition to clean capital more expensive (IPCC, 2014; IRENA, 2017a). Second, a sudden and unexpected tightening of carbon emission policies (Batten et al., 2016) or sudden changes in expectations in the presence of tipping points (Krugman, 1991) can lead to abrupt repricing of fossil fuel assets. This situation can result in a negative supply shock through changes in energy use and second-round effects in financial markets.[3] Financial institutions such as the Bank of England, the Dutch Central Bank (DNB), the Inter-American Development Bank (IDB), and the European Systemic Risk Board (ESRB) have identified the mispricing of stranded asset risk as a potential systemic risk and threat to financial stability.[4]

Therefore, we analyze the interaction between investors' expectations and the development of climate policies. Investors' reactions to new policies depend on their prior

[1]For example, see the report by HSBC on "Coal and Carbon. Stranded Assets: Assessing the Risk," picking up on the 2011 report by the Climate Tracker Initiative on "Unburnable Carbon - Are the World's Financial Markets Carrying a Carbon Bubble?"

[2]See Caldecott (2017) for various definitions of the term "stranded assets".

[3]Weyzig et al. (2014) analyze the risk associated with the carbon bubble, and conclude that a slow and uncertain transition to clean energy is likely to be costlier than a quick transition.

[4]See Batten et al. (2016); Schotten et al. (2016); Caldecott et al. (2016); European Systemic Risk Board (2016). Bank of England governor Mark Carney warns "..., once climate change becomes a defining issue for financial stability, it may already be too late" (speech given at Lloyd's of London, September 9,2015). To mitigate the risk, the Finance Ministers and Central Bank Governors of the Group of Twenty (G20) requested the Financial Stability Board to create an industry-led Task Force on Climate-Related Financial Disclosures (TCFD, 2017). The private sector is becoming increasingly aware and active as well, with, for example, the rating agency Moody's announcing that it will analyze firms' carbon transition risk in its credit ratings (Moody's, 2016).

expectations, which, in turn, are shaped by previous policies. This interaction is central to the current paper: What are investors' priors regarding stranded asset risk, and (how) do these priors change when climate policy proposals are announced? In particular, we analyze (i) whether investors have already priced in expected losses due to the carbon budget, (ii) whether they only respond to concrete policies, and (iii) whether they expect firms to be financially compensated for stranded assets. To answer these questions, we exploit the gradual development of a climate policy proposal in Germany targeting lignite assets and investigate how adjustments of this proposal have affected the market valuation of firms active in electricity production. We find that investors did not react to announcements of the initial "climate levy" proposal, which was directed at stranding lignite assets by charging an extra fee on carbon emissions (Stage 1). Investors also did not respond when the proposal transformed into a compensation mechanism (Stage 2), paying plant owners for not running their units. Only announcements that the compensation mechanism may not go through due to violating state aid rules (Stage 3) resulted in a significant and negative reaction. Our findings show that investors do care about the stranded asset risk, but with an expectation of a compensation mechanism.

Our analysis starts from the notion that the evolution of climate policies and the expectations of investors are interrelated. First, climate policies and policy proposals provide signals that shape how the investors percieve the stranded asset risk. For instance, setting a price on CO_2 emissions or imposing a cost on fossil resource extraction[5] can reduce demand, slow down investment in fossil infrastructure, and cause asset stranding. Alternatively, policies addressing fossil-fuel reductions may compensate fossil-fuel owners for leaving their reserves unburned. For example, Harstad (2012) proposed that, in the absence of a global climate agreement, "the coalition's best policy is to simply buy foreign deposits and conserve them".[6] Second, investors' reactions to policy signals depend on their prior expectations regarding the likelihood of asset stranding and the credibility

[5]For instance, by reducing subsidies or imposing taxes on production, exports, or capital rents (Faehn et al., 2014; Richter et al., 2015; Sinn, 2008).

[6]Such as the failed compensation attempt for the oil under Yasuni National Park in Ecuador. Compensation mechanisms have been suggested in various contexts, such as to enable an international climate agreement, reduce the cost of emission reductions, prevent carbon leakage, and avoid stranded assets (Harstad, 2012; Peterson and Weitzel, 2014; Collier and Venables, 2014).

of climate policy announcements. For example, they may have already devalued assets following information on the carbon budget implied by the Paris Agreement, or they may find it difficult to translate the concept of a carbon budget into stranded asset risk.[7] In the latter case, they would wait for further information on climate policies with clear asset stranding implications. Even the announcement of climate policies does not necessarily lead investors to reassess the likeliness of asset stranding, if they expect a compensation mechanism. The policy proposal we investigate provides the opportunity to disentangle the effects of these policy signals and expectations. By tracking the stock market response to different stages of the proposal, we can draw conclusions about investors' prior expectations and how they evolved in the course of the policy's development.

Our baseline estimation strategy is a short-run event study analysis. We investigate whether there are abnormal returns to the assets of three publicly listed energy companies that can be associated with the three stages of the policy proposal.[8] The pattern in the reactions to the different stages of the proposal helps us to identify whether an individual event surprised the investors. Furthermore, we test for effects in the power futures market to establish surprise empirically. Finally, we provide anectodal evidence for our empirical findings on the presence of surprise. We provide an extensive robustness analysis related to the identification of the event effects. First, we conduct placebo tests for the nonevent days just prior to the event days to verify the model's performance in predicting the counterfactual returns. Second, as an alternative to using a market price index to control for average market conditions, we estimate a synthetic portfolio aiming to produce a counterfactual control unit.[9] These estimations show that our results are not driven by the endogeneity of the market price index to the event shocks. Third, in order to control for industry-wide shocks, we use an energy utility company without any lignite-related assets as the control unit, leading to a difference-in-differences estimation of abnormal

[7]See Rook and Caldecott (2015) for how a wide range of cognitive biases in the decision-making process of oil industry managers can hamper risk perceptions and exacerbate the risk of asset stranding.

[8]Short-run event study methodology has been a widely employed approach in identifying how specific events affect asset returns. See MacKinlay (1997) for a comprehensive description of event study methodology.

[9]See Abadie and Gardeazabal (2003) and Abadie et al. (2010) for the synthetic control approach. We apply this approach to the classic short-run event study methodology. See Guidolin and La Ferrara (2007) for a similar approach.

returns. Finally, by using a news search engine, we identify a small number of potentially confounding events and verify that our results are not driven by these events.

Our paper contributes to the literature on empirical assessments of market reactions to emission reduction policies, often in the form of event studies. Lemoine (2017) and Di Maria et al. (2014) find that market players do act in anticipation of demand-side policies. Ramiah et al. (2013) and Linn (2010) show that stock investors react to announcements of national carbon emission pledges or the introduction of emission trading programs, respectively. Koch et al. (2016) find evidence that regulatory events drove EU ETS allowance prices. In the German power market context, Oberndorfer et al. (2013) investigate the stock market effects of voluntary actions such as the inclusion of firms in a sustainability stock index. However, to date, investor expectations with regard to specific policies directed at stranding assets or to compensation mechanisms have not been studied.

There are few papers investigating empirically how investors price in unburnable carbon risk. Batten et al. (2016) conclude that the announcement of the Paris Agreement in December 2015 had a positive effect on the valuation of renewable energy companies, but no significant effect on fossil fuel companies. Mukanjari and Sterner (2018) report similar results both for the Paris Agreement and the U.S. presidential election in 2016. Griffin et al. (2015) find that the publication of the Meinshausen et al. (2009) article in *Nature* led to a statistically significant, yet fairly small, reduction in the stock returns of oil and gas firms. They mention several reasons why this effect might be so small. One reason is investors' expectations with respect to technological developments: this is what Byrd and Cooperman (2016) examine, concluding that investors are aware of the relevance of carbon capture and storage (CCS) in allowing continued carbon use, but that they have already priced in stranded asset risk. A second potential reason is that investors are more concerned with specific energy policies, which is what this article examines in detail.

The remainder of the paper is organized as follows: Section 2 describes the development of the specific German policy proposal and the affected companies. In Section 3, we present a theoretical discussion on the potential effects of the proposed policies.

In Section 4, we present different scenarios with regard to investors' expectations. The empirical methodology is outlined in Section 5, and Section 6 presents the main results. We present the robustness tests in Section 7. Section 8 presents a general discussion of our results, and Section 9 concludes.

2 Event Description

We track investors' reactions to each of the three steps in the development of a German climate policy proposal known as the "climate levy" (Klimabeitrag) that was first publicly announced in March 2015. The development of this proposal provides a convenient empirical setting for investigating investors' expectations. Each stage in the development of this proposal represents a different event within our analysis. The first stage of the policy development, the introduction of the climate levy proposal, was designed to retire lignite assets. The second stage is the amendment of the proposal to include a compensation mechanism. In the third stage, the compensation mechanism came under official scrutiny for being inconsistent with the EU state aid rules.

Event study methodology is a widely employed approach to analyze the effects of regulatory changes or policy announcements (Lamdin, 2001). In regulatory event studies, it is necessary to identify the potential dates on which new information might have changed investors' expectations (Binder, 1985a). We extensively examined several news search engines to identify the date on which the related information regarding each stage of the proposal might have been publicized in the media. In the next stage, we carefully searched for (i) prior events which might have led to information leakages, and (ii) later events which might represent an additional piece of information for investors' assessment. Our search resulted in three or four announcement dates for each stage. Table 1 presents the stages of the policy proposal and the announcement dates in their chronological order. In the remainder of this section, we describe the proposal development, our strategy to establish surprise for each of the stages of the proposal, and some important characteristics of the affected companies.

Table 1: Event Dates

No	Date	Events and Announcements
		Stage 1: Climate levy proposal
(1a)	March 20	First news on climate levy proposal
(1b)	March 26	Climate levy proposal presented in parliament
(1c)	May 19	Ministry provides new, less stringent proposal for climate levy
		Stage 2: Security reserve proposal
(2a)	May 23[a]	IG BCE trade union presents proposal of turning lignite plants into capacity reserve
(2b)	May 28	Media reports that Ministry is positively considering the IG BCE proposals
(2c)	June 24	Minister debating between two options: climate levy and security reserve. Coalition summit will decide on July 1
(2d)	July 2	Press reports: Coalition summit decided on security reserve
		Stage 3: State aid assessments
(3a)	July 23[b]	Academic service of German Parliament assesses security reserve as violating EU state aid rules
(3b)	August 14	Media reports on the state aid assessment
(3c)	September 14	European Commission considers state aid procedure

The source is LexisNexis and own research. All dates are in 2015.
[a] The date of Announcement (2a) corresponds to Saturday. In our estimations, we take its announcement date as the following Monday. Note that events (2a) and (2b) are very close and may overlap depending on the event window.
[b] This is the date of the report; it seems that the media reports on August 14 were the first public news on this topic.

Stage 1: Climate levy proposal - uncompensated policy: In March 2015, the German Ministry of Economy and Energy presented its first proposal of the climate levy legislation. This proposal suggests charging an extra levy on CO_2 emissions from all power generating units older than 20 years whose emissions exceed a certain yearly threshold (a levy-free allowance). The aim of the proposal was to save 22 million tons of CO_2, as Germany needed to cut emissions from the electricity sector by that amount in order to reach its national emission reduction targets. The climate levy proposal directly targeted the stranding of assets by focusing on old units and incentivizing non-use if the allowance is exceeded. The excess levy was to be applied independently of technology. Therefore, the most emission-intensive energy carrier, lignite, would have been the most, or the only one, affected.[10]

[10]For the details and implications of the climate levy, see, e.g., Peterson (2015), Bundesministerium

German lignite power plants are designed to provide base load electricity. They are all situated next to mines, since lignite is essentially not transported over long distances due to the high transport cost per energy content. Often, operators of lignite power plants own and operate the mines. Thus, if the power plant is not run, then the fuel input of the plant is left in the ground. Consequently, a policy targeting CO_2 emissions from lignite strands the power plant assets as well as their fuel resources.

The climate levy proposal was the first stage of the policy development and we classify this proposal as an "uncompensated policy." Unsurprisingly, the proposal sparked protest among industry, trade unions, and politicians. In response, the Ministry presented an amended proposal in May 2015, permitting operators to transfer the allowances to other installations, and allowing some flexibility in the levy price. However, this was not enough to placate the levy's opponents.

Stage 2: Security reserve proposal - compensated policy: Only a few days later, the trade union for mining, chemicals, and energy (IG BCE) presented its own proposal, which was to turn six Gigawatts of lignite capacity into a capacity reserve. That is, they suggested to take this capacity out of the regular electricity market, pay them for holding capacity ready, and use the capacity only in the case of unexpected shortfalls. This marks the beginning of the second stage of the policy development. Following IG BCE statements that the Ministry was positively considering this alternative proposal (May 28), various newspapers reported that the climate levy would not be introduced (June 6). On June 24, Minister Gabriel declared that both options were currently on the table for discussion and that the coalition summit would decide. On July 2, 2015, the federal coalition decided at its energy summit not to introduce the climate levy, but a security reserve (Sicherheitsbereitschaft, literally security readiness[11]), mothballing 2.7 Gigawatts of capacity.[12] The targeted units were equivalent to 13% of installed lignite capacity and were supposed to be compensated for their foregone revenues (to be financed via network

für Wirtschaft und Energie (2015) and Oei et al. (2015). Lignite provided 24% of German electricity production in 2014.

[11]The term "capacity reserve" (Kapazitätsreserve) described another mechanism in the energy market legislation and thus could not be used to describe the mothballing of lignite power plants.

[12]The term "mothballing" is used for power plants (or any other production facilities) that are not in operation, but preserved for potential future use.

fees) until they were gradually decommissioned.

Stage 3: State aid assessments - challenge to the compensation: It turned out that the compensation proposal had to overcome another hurdle, which brings us to the third stage. In July 2015, the German Parliament academic service concluded that the security reserve could violate EU state aid rules. *Spiegel online* was the first to report this state aid assessment on August 14, stating that it could cause the security reserve plans to fail. On September 14, the European Commission announced that it was considering a state aid procedure on the security reserve plans. We classify this news as a "challenge to the compensation".

Surprise. Event studies aim to understand whether investors use new information revealed by an event (surprise) in their valuation of firms. In the absence of any confounding events, a significant market reaction indicates that the announcement of interest contains a surprise element. On the other hand, absence of reaction might simply mean that the announcement does not constitute a surprise. Our empirical design is a novel approach which helps to understand the nature of surprise element in the announcements by tracking reactions to a sequence of related events. The idea is that, significant reactions for some events inform us about the expectations of investors in certain periods, which can be useful to figure out the expectations of investors before and/or after a related event with no market reaction. This indirect information can be helpful to understand whether an event with no market reaction did contain a surprise element or not.

In such a sequential event study analysis, it might be important to establish surprise for the first announcement, as there is no previous event to track a change in expectations. Press reports on the first announcement of the proposal give interesting insights. According to the weekly newspaper *Der Spiegel*, the first public news on the climate levy proposal were the result of a leak a couple of days before the official presentation of the proposal (see Table 1). Minister Gabriel, of the Social Democrats (SPD), had not even informed the coalition partner (the Christian Democrats, CDU) about the proposal. Irritated by this "rush" without prior consultation, the CDU called off a planned meeting of energy experts from both parties.[13] If not even all government members were aware of the proposal, it is unlikely that markets had prior knowledge of it. In Appendix A, we show that this point is supported by the googling trends for the term "Klimabeitrag" (climate levy) in Germany between January and September 2015. The patterns show that this was not a marginal topic — we observe a general public interest in the issue coinciding with the event dates we identified. The term "Klimabeitrag" became a trend only after the first news on the proposal which we identified. The search pattern does suggest that the first announcement of the proposal came as a surprise. The details are provided in Appendix A.

After presenting our baseline results in Section 6, we empirically establish whether there is a surprise or not for all stages of the policy proposal by following three strategies: (i) analyzing a sequence of related events as explained earlier, (ii) providing an extensive analysis to rule out that significant market reactions are not driven by confounding events, and (iii) tracking the intensity of market activity for electricity futures, based on the idea that the initial proposal would result in a significant reduction in baseload electricity capacity after 2016. The third strategy turns out to be particularly useful in establishing surprise for the initial stage. Our empirical findings on the presence of surprise are in line with the anecdotal evidence presented previously.

Companies. We focus on the three publicly listed German companies that were active in the lignite business in 2015: RWE AG, E.ON SE, and EnBW AG.[14] The climate levy proposal targeted plants older than 20 years and was intended to be implemented in 2017. Considering the share of each firm's lignite plants that were commissioned before 1997 in its overall electricity generation capacity, RWE was the most lignite-intensive electricity producer. The share of lignite plants older than 20 years in RWE's total capacity was 31% by 2015. For E.ON, this share would have been 8%.[15] On the other hand, EnBW holds shares only in one plant that was commissioned in 1999 and thus the policy proposal

[13]See `http://www.spiegel.de/wirtschaft/service/gabriel-neue-klimaschutzabgabe-fuer-kohlekraftwerke-geplant-a-1024554.html`.

[14]Two more firms were operating with lignite: Vattenfall GmbH and Mibrag mbH. As they are not publicly listed, we cannot consider them in the event study.

[15]The underlying data for these calculations is described in the next section.

would not affect EnBW. Moreover, in contrast to RWE, which largely owns the lignite mines next to its plants, E.ON and EnBW only operate the power plants and buy the fuel from a mine operator. Therefore, their stranded asset risk is limited to their power plants, whereas RWE would have had to strand its fossil assets as well.

While the climate levy proposal did not target specific plants (apart from selecting by age), the security reserve proposal clearly specified the individual plants scheduled for mothballing.[16] Of the three publicly listed companies, only RWE was affected by this bill: two of its units in Frimmersdorf were scheduled to be mothballed on October 1, 2017, two units in Niederaußem on October 1, 2018, and one unit in Neurath on October 1, 2019. The final decommissioning is always scheduled for four years later. Nevertheless, E.ON was impacted by the coalition decision on the security reserve because it implied that the climate levy would not be introduced. All announcements related to a potential state aid procedure against compensation plan are relevant for all lignite-owning companies because they introduce uncertainty about future policies.

3 Theory

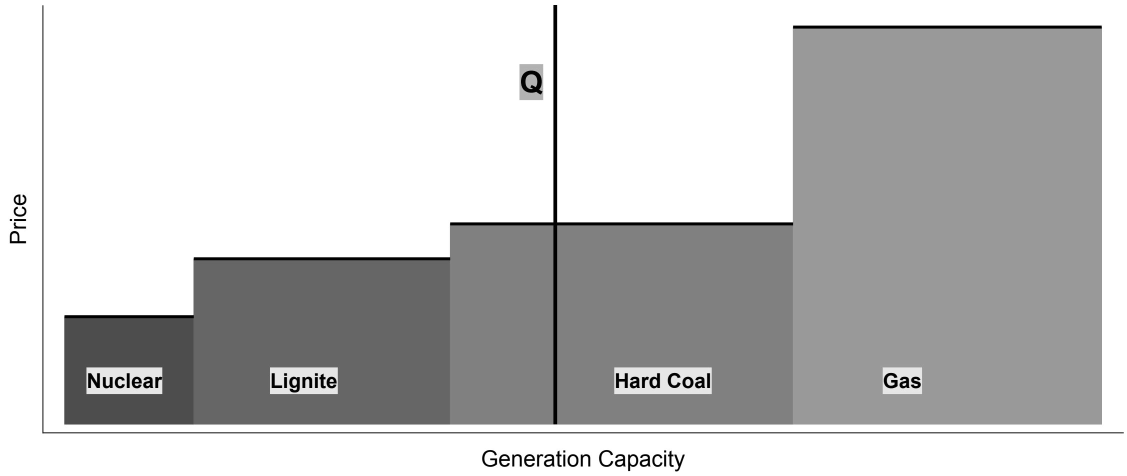
In this section, we use a simple theoretical setup in order to provide intuition for the potential effects of the proposed policies and give a feeling for the magnitude of their effects on the profits of the firms. We focus on RWE for brevity. In the following, we start by describing the economic environment, how we map this environment to data, and our policy scenarios. Finally, we present the theoretical predictions from our scenario analyses.

3.1 Environment

We assume that demand is fully inelastic and firms operate in a perfectly competitive market. Each firm determines output by maximizing profits subject to the capacities of their plants. The number of plants owned by a firm and their generation capacities are

[16] See Table 6 in the Appendix for a list of units to be transferred into the security reserve.

Figure 1: Electricity Supply and Demand



Notes: This figure illustrates the demand and supply curves implied by our theoretical setup. The technologies are ranked by their average variable costs calculated from IEA (2015).

exogenous. In this setting, the so-called merit order of various technologies determines the supply curve, such that the capacity with lower marginal cost of producing power has priority in meeting the demand for energy. In our baseline analysis, we assume that the marginal cost of producing electricity is constant and technology specific. Generated electricity from renewables has priority in meeting electricity demand, because renewable electricity generation is characterized by low operating costs and high volatility in its capacity utilization. Therefore, market clears where conventional power capacity meets the residual load given by total load minus electricity generation from renewables.

We illustrate this theoretical framework in Figure 1, where Q stands for hourly residual demand. We rank the conventional technologies by their average variable costs (AVC), which we obtain from the IEA report "Projected Costs of Generating Electricity 2015" (IEA, 2015).[17] The IEA's data imply that nuclear comes first in the supply schedule, followed by lignite, hard coal, and gas. We provide further details about the AVCs in the next subsection. Appendix B.2 presents further empirical evidence supporting the merit order of these conventional technologies.

In the depicted situation, the marginal technology is hard coal, such that the market equilibrium is determined by the marginal cost of producing power from hard coal. The infra-marginal technologies are nuclear and lignite, which operate at their full capacity.

[17]See Tables 3.9, 3.10, and 3.11 in IEA (2015).

They become marginal technologies at hours with low residual load. The gas capacity operates at peak-load hours when the residual demand is high.

3.2 Estimation of the merit order curve

In this section, we describe how we map our economic environment to data. We conduct this analysis in two steps. First, we determine the ranking of conventional technologies in the supply schedule as breifly explained in the previous subsection. Second, we estimate technology specific supply curves by using data on market prices. Next, we explain each of these steps in detail.

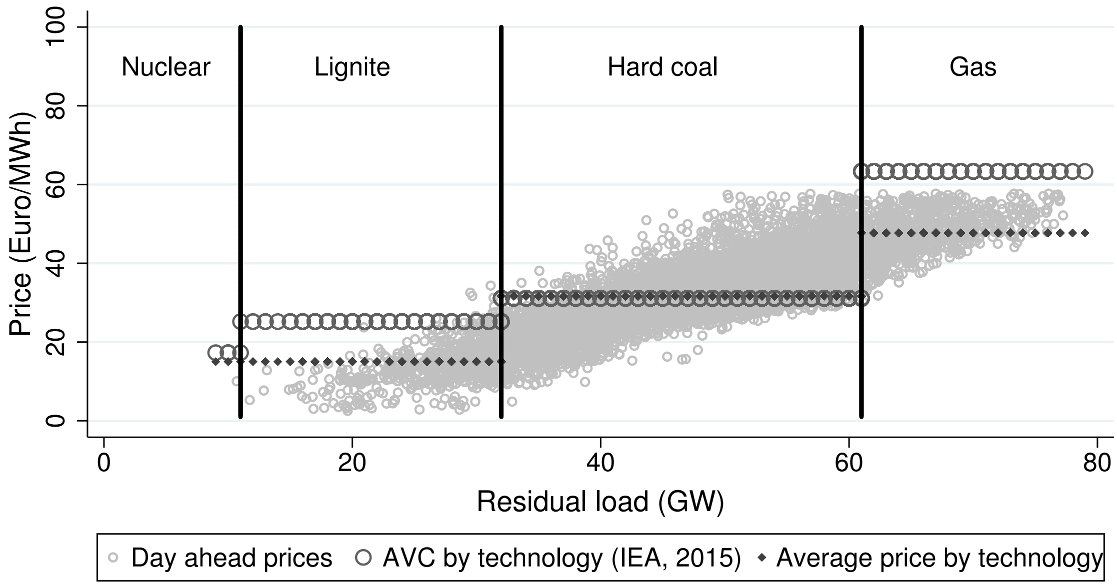
As we will illustrate later in this section, our policy scenarios mainly change the ranking of some part of the lignite capacity in the supply schedule. Therefore, we need to be able to identify which generation capacities are subject to our policy shocks. Unfortunately, we do not have the required data to achieve this identification at the level of capacity unit or at the plant level. However, our assumption of technology-specific constant marginal cost enables this analysis in two ways. First, we can rank the conventional technologies by their AVCs from the IEA data. Second, as the marginal cost is assumed to be constant for each technology, which part of the lignite capacity is replaced by the shock is irrelevant. The AVCs based on the IEA data are depicted in Figure 2.[18] We impose the illustrated ranking of conventional technologies throughout our analysis. However, we do not prefer to use the AVCs themselves as an approximation for the merit order curve. The reason is that the AVCs are not completely in line with the market outcomes within our theoretical framework, which we show in the following.

Under an inelastic demand assumption, the functional relation between electricity prices and residual load traces a supply curve.[19] Figure 2 also presents the observed

[18]In calculating these average variable costs, we include the fuel, carbon, and operational and maintenance costs reported in IEA (2015). However, we set the carbon price to \$10 per tonne of CO_2 which is a rough approximation of the ETS price in 2015, instead of a \$30 per tonne of CO_2 carbon price assumed by IEA. The range of technological capacities are given by their net installed generation capacities obtained from the website of Fraunhofer Institute for Solar Energy Systems (ISE). See https://www.energy-charts.de/index.htm.

[19]See, for example, Bessembinder and Lemmon (2002) and Cludius et al. (2014) for estimations of electricity supply curve from data on market outcomes.

Figure 2: Electricity prices and residual load



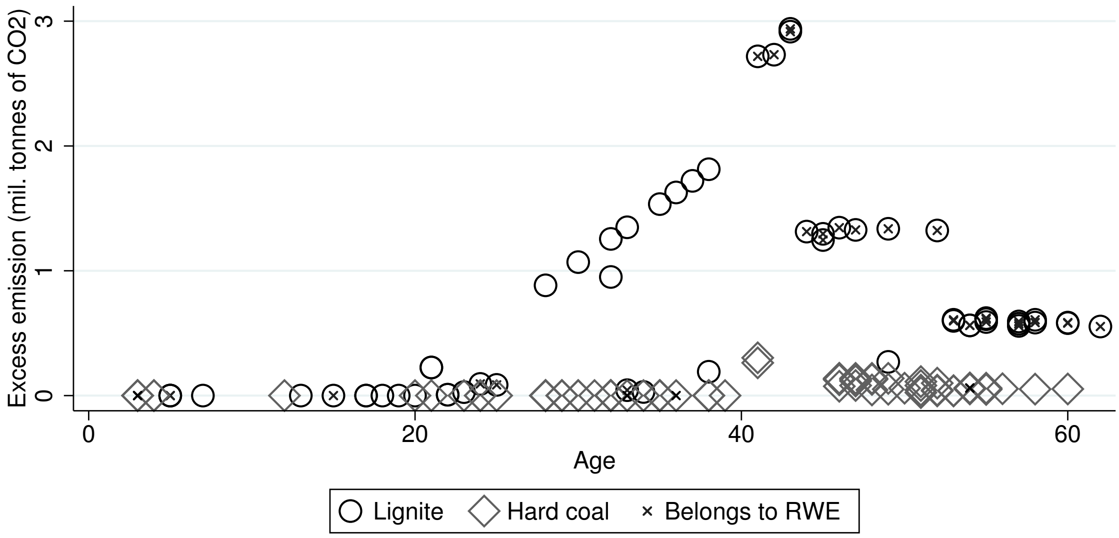
Notes: This figure illustrates the hourly prices and residual loads in 2015 for Germany. The prices are the day-ahead prices in the EEX market, which are truncated at the upper and lower 2$^{\text{nd}}$ percentiles. The technologies are ranked by their AVCs, which we obtain from IEA (2015). The residual-load range that is met by a specific technology is determined by the generation capacities of technologies. The residual load is given by total load minus generated electricity from renewables.

prices and the average prices within each technological supply range.[20] The average price where hard coal is assumed to be the marginal technology is quite close to the AVC of hard coal. However, there are considerable differences between the AVCs and the average prices in the case of lignite and gas. Therefore, we conduct our analysis with the average prices by maintaining the technology-specific constant marginal cost assumption. We discuss the implications of this assumption later in this section, and provide results from relaxing it in Appendix B.4.

One obvious problem in Figure 2 is that there are not enough observations for the nuclear capacity, which means that it is rarely the marginal (price-setting) technology. We circumvent this problem by assuming that its marginal cost is equal to the minimum of the predicted supply curve for other technologies, which corresponds to that of lignite capacity.

[20]We obtain the residual load and price data at hourly resolution from the Open Energy Modeling Initiative (OEMI, 2019). The prices are the day-ahead prices in the European Energy Exchange (EEX) for the German power market. Appendix B.1 presents further details about this dataset.

Figure 3: Excess emission by plants subject to the climate levy



Notes: This figure plots the level of excess emissions in 2015 from each plant in Germany against their ages. Diamonds indicate hard coal plants, and circles indicate lignite plants. The plants of RWE are crossed. There are three more plants over 70 years old. They are not shown in this figure for clarity. They have very low or zero excess emissions, and they do not belong to RWE.

3.3 Policy shocks

We go on by quantifying the policy shocks to the economic environment described in the previous subsection. The climate levy would apply to annual emissions in excess of 7 million tonnes of CO_2 per GW installed capacity by plants over 20 years old. The cost of exceeding this limit was as high as 20 Euros per tonne of CO_2. The levy-free emissions would be lower for older plants, leading to a cap of 3 million tonnes for plants over 40 years old.[21] We use the 2014 plant level data from the Federal Network Agency (Bundesnetzagentur), which provides the nameplate capacities of each plant in Germany together with their construction dates. In our calculations related to RWE, we take into account the plants owned by RWE Generation SE, RWE Innogy GmbH, and RWE Power AG.

We assume that the levy-free emission level for 21 and 41 year-old plants are 7 million and 3 million tonnes of CO_2, respectively. We apply linear interpolation to obtain in-between values. In our scenario analysis, we assume that the climate levy applies to emissions above these estimated limits. We also assume that emission per capacity is

[21]See Oei et al. (2015) for further details.

constant for each technology, and calculate hourly emissions by using the annual data on emissions per installed net capacity provided at the ISE website. The results from these calculations are presented in Figure 3, where each point represents a plant. Lignite plants are indicated with circles, hard coal plants are indicated with diamonds, and the plants of RWE are crossed. The vertical axis indicates excess emissions of a plant that is subject to the fee.

There are two noteworthy observations in Figure 3: First, the hard coal capacity is almost unaffected. Second, the share of the affected capacity of RWE in overall affected capacity is very high. Based on our calculations, 48 out of 58 lignite plants and 73 out of 79 hard coal plants were over 20-years old by 2017. However, the policy is hardly binding for the hard coal capacity as the average emissions from hard coal plants per GW-installed capacity were 3.4 million tonnes of CO_2 in 2015. According to our calculations, the levy would be binding for less than 4% of the hard coal capacity. Therefore, we ignore this point in our analysis. On the other hand, the average emissions from lignite plants per GW installed capacity were 7.5 million tonnes of CO_2. As a result, 29% of the lignite capacity would be subject to the climate levy. Taking into account the average emissions per MWh of generation from lignite plants, the marginal cost of affected lignite plants would increase by 28 Euros/MWh.[22] This fee would apply to 41% of RWE's lignite capacity.

The merit order effect of the climate levy is indirect through the resulting change in prices. On the other hand, the security reserve proposal implies a direct change in the merit order. This policy scenario phases out 2.7 GW lignite capacity and moves it into a security reserve. In our analysis, we ignore the latter implication and simply remove this capacity from the supply schedule.[23]

[22]We obtain emission and generation data for lignite plants from the ISE charts, and calculate average emissions per MWh of generation.

[23]See Table 6 in Appendix B.3 for the list of units to be transferred into the security reserve.

3.4 Merit order effects

Next, we explain how our policy shocks affect the estimated supply curve. Figure 4 illustrates the implications of our policy scenarios on the supply curve. In this figure, the capacities that are affected by the policies and the generation capacity by technology are based on our dataset. On the other hand, we set the cost levels in order to clarify the exposition. However, the illustration preserves all the qualitative implications of our calculations. The average residual demand for conventional power capacity in 2015 is indicated with Q. The figure shows that, hard coal is the marginal technology at the average demand. This is in line with the higher variability of generation from hard coal plants in Germany. We support this result with further empirical evidence in Appendix B.2.[24]

The climate levy scenario leads to a drastic change in the merit order curve as illustrated in the first panel of Figure 4. A considerable hard coal capacity replaces the affected lignite capacity, which leads to a higher average cost of meeting the average load. The affected lignite capacity is now ranked just prior to the gas capacity on the merit order curve. The second panle illustrates the effect of security reserve proposal. It phases out 2.7 GW of lignite capacity. As a result, the hard coal and gas capacities shift left on the supply schedule.

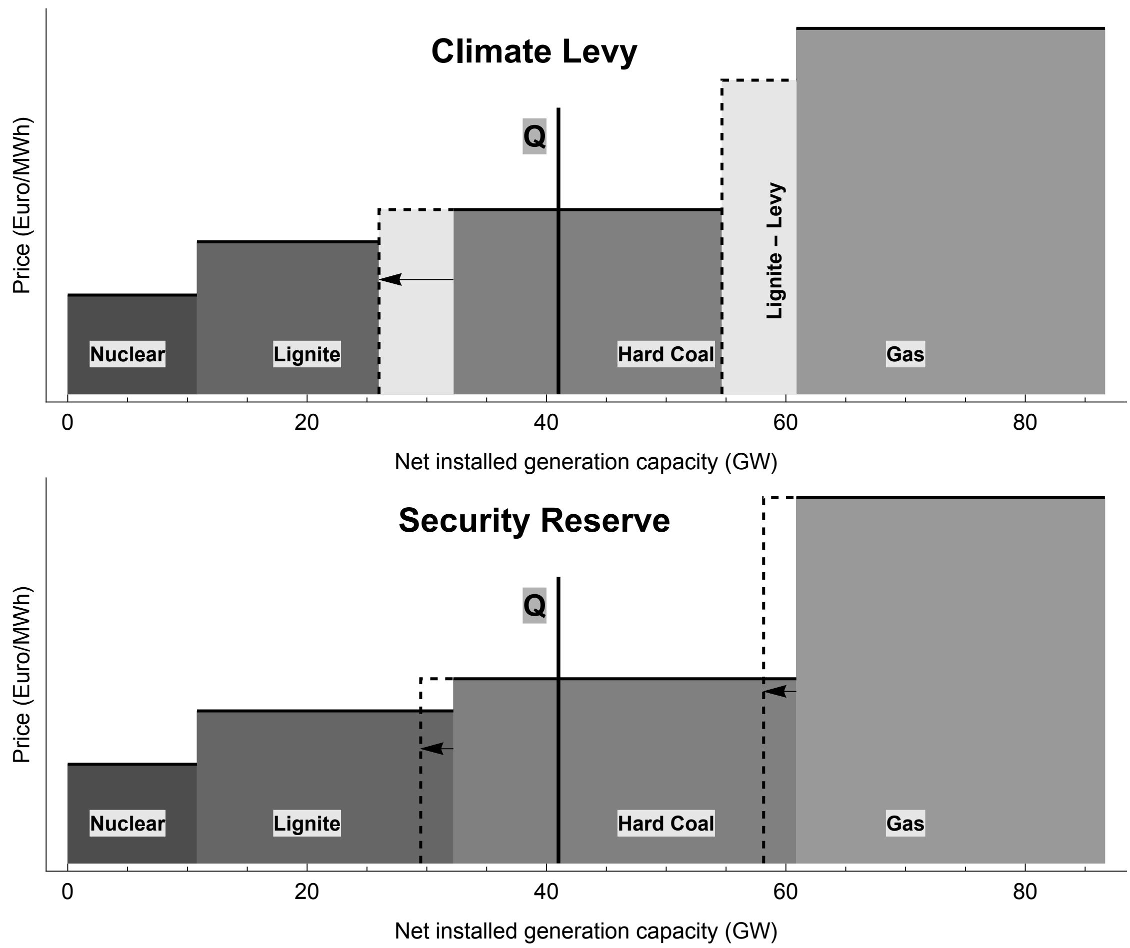
These policy scenarios do not affect the market price at the average load instant. Hence, at the average load, there is no profit change for the capacity ranges that are unaffected by the policy, but there is a negative profit effect due to the replacement of the affected lignite capacity with hard coal capacity. We present the profit effects at each load instant in the following subsection.

3.5 Profits

We calculate the overall profit effects by assuming that the total profit from each technological capacity is shared among firms based on their technology-specific capacity shares.

[24] Also see the charts presented on the website of ISE for the variability of generation (https://www.energy-charts.de/index.htm).

Figure 4: Merit order effects

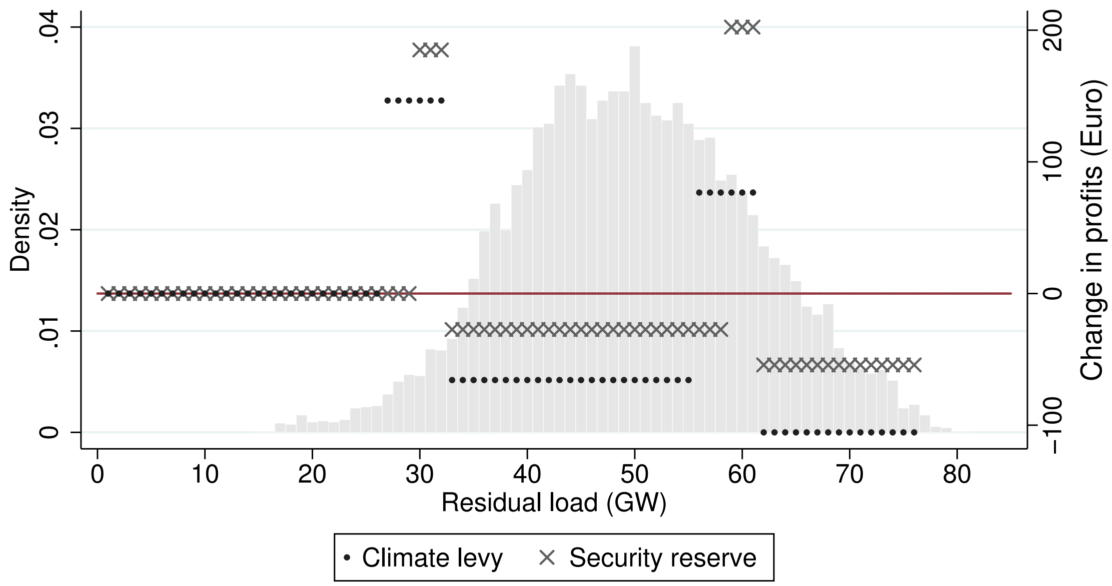


Notes: This figure illustrates the effects of the proposed policies. Affected capacities and generation capacities are based on the 2015 data for Germany. Marginal costs are not based on data, but chosen to clarify the exposition. The first panel illustrates how the climate levy relocates a significant amount of lignite capacity on the merit order curve. The second panel illustrates the phase-out plan due to the security reserve proposal. Q is the average hourly load in 2015.

Figure 5 displays the density of hourly load over 2015 and the absolute change in RWE's profits at each load value. When we calculate the profits for each value of load, and take weighted average with respect to its density, we find that the climate levy causes 18% profit loss on average, and the security reserve scenario results in 5% average loss in profits.

Figure 5 depicts the profit effects at each level of hourly demand, which can be summarized in three categories: First, there is no change in the profits at the hours when the marginal technology is nuclear or unaffected lignite capacity. Second, at the load instants where the shift in the supply curve causes a change in the marginal technology, the firm makes positive profits from running its infra-marginal units. For example, the

Figure 5: Profit effects



Notes: This figure illustrates the density of hourly load over 2015 and the absolute change in hourly profits at each load value due to climate levy and security reserve scenarios. The residual load is given by total load minus generated electricity from renewables.

nuclear capacity runs with much higher absolute profits at these hours. There are two occasions of positive profits: one is where the lignite capacity is replaced by the hard coal capacity, and the other one is where the hard coal capacity is replaced by either the lignite capacity in the climate levy scenario, or the gas capacity in the security reserve scenario. The density of such hours is less than half of that of an hour with the average load. Hence, although the positive profit effects are high at these load instants, their weights are small. Third, the profits are negative for all other values of load which covers the mass and the right tail of the distribution.

A noteworthy point in Figure 5 is related to the hours where the hard coal capacity is replaced. At those hours, there are two countervailing effects on the profits. First, the post-policy prices are higher, leading to positive profits from infra-marginal technologies. Second, the post-policy marginal cost of the capacity where hard coal replaces lignite is higher, which exerts a negative pressure on the profits. The net effect seems to be positive for both scenarios. However, it is much smaller for the climate levy scenario. The reason is that the marginal cost of affected lignite capacity is not much higher than the marginal cost of the replaced hard coal capacity.

3.6 Remarks and summary

The security reserve proposal includes a compensation for the affected capacity. The proposed compensation amounts to 1.61 billion Euros for the five years that this capacity is used as a security reserve just prior to their scheduled decommissioning dates. According to our calculations, the implied subsidy rate of the compensation is 13.38 Euro/MWh.[25] This means that the policy compensates the decline in profits due to each unit of retired capacity at this rate. The 13.38 Euro/MWh subsidy for RWE's retired capacity compensates half of its profit loss at the average-demand, which can be seen in Figure 5. The net effect of the security reserve policy on RWE's total profits is a slight increase in profits by less than 1%.

To summarize, our theoretical analysis predicts that (i) the climate levy proposal in the first stage leads to an 18% loss in the RWE's profits, and (ii) the retirement of lignite plants in the security reserve scenario results in 5% profit loss, which is fully restored with a compensation. In the third stage of the proposal, the security reserve scenario faced a legal challenge that the compensation plan could be against the EU state aid rules. This event increased the probability of an uncompensated policy, such as the climate levy in the first stage.

In our analysis, we assume constant marginal cost per technology, and use the average prices to approximate the merit order curve. An alternative way is to allow for non-constant marginal costs by fitting technology-specific lines to the market data. We prefer the former method for three reasons. First, it is much easier to illustrate the effect of these policy scenarios on the supply schedule, which is the main goal of the current section. Second, each capacity unit of lignite would have different marginal cost under non-constant marginal cost assumption, whereas we do not have data to identify the lignite units affected by the climate levy. This point is not important under a constant marginal cost assumption. Third, the estimations of a linear supply curve suffers from simultaneity. As a result, estimated slopes based on market data can be biased. Proper

[25]We assume that the decommissioning dates provided in Table 6 in Appendix B.3 are binding independent of the policy, and the compensation is paid for the energy that the capacity in the security reserve can produce for the five years just prior to their scheduled decommissioning dates.

Table 2: Scenarios for Investors' Priors and Reactions

	Scenarios	**Reactions to...**		
		Uncompensated policy	Compensated policy	Challenge to compensation
0	Don't care	0	0	0
1	Have not priced in stranded asset risk before, but react to policies	−	+	−
2	Have priced in expected loss, but are surprised by compensation	0	+	−
3	Have priced in expected loss and compensation	0	0	−

estimation of the supply curve is beyond the scope of our paper. With a positively-sloped supply curve, however, the policy shocks lead to an increase in prices at each point that the supply curve shifts to left. An increase in equilibrium prices affects profits positively, in particular for infra-marginal nuclear and lignite capacities. Therefore, relaxing the constant marginal cost per technology assumption might yield lower profit effects in absolute terms. We illustrate this effect in Appendix B.4 based on a naive supply curve estimation.

4 Potential Reactions and Investors' Priors

We will draw conclusions about investors' initial beliefs from their reactions to the different stages of the policy development. Table 2 outlines plausible belief updating scenarios. *Scenario 0* is no reaction: here, investors simply do not care about stranded asset risk and do not react to any policy proposals or related news. In *Scenario 1*, the investors' prior is that unburnable carbon is of no concern. However, they do care about stranded asset risk induced by specific policies, and react to such news. They are positively surprised by the compensation mechanism and negatively by its challenge. In *Scenario 2*, investors have already priced in stranded asset risk due to unburnable carbon: for example, they are aware of a nationwide or worldwide emission reduction target and have already considered this overall target in their firm valuation. Therefore, a policy introduced to achieve the target does not impact their valuation of the affected firms. However, the compensation mechanism is unexpected for these investors and they value it positively.[26] When the compensation is challenged, they adjust their valuation downward again. Finally, in *Scenario 3*, investors do care about stranded asset risk, but they expect firms to be compensated. When the Ministry announces the uncompensated policy, they already expected a policy move and they still expect a subsequent compensation to follow. Therefore, they do not believe that the announcement will affect the firms economically, and show no reaction. The compensation plans are not surprising, either, and investors do not adjust their firm valuation. However, the challenge of the compensation is a surprise, and causes investors to adjust firms' values downward.

Table 2 lists the scenarios that we find likely and logically consistent. It is not a complete list of potential reactions and potential interpretations for each event. Note that, absence of surprise is already one part of the story in some of our scenarios. We provide a detailed analysis related to the surprise content of the events in Section 6 after presenting our results.

5 Empirical Methods

We conduct a short-run event study analysis where we investigate whether there are abnormal returns associated with the events. Consider the following specification to estimate the normal market performance of a single asset: $r_t = X_t\beta + \epsilon_t$, where r_t is the continuously compounded return of the asset at the trading date t, which is the daily change in the logarithm of asset prices. The normal performance of the asset is predicted by the vector of covariates X_t. The coefficient vector (β) and the error term (ϵ_t) are asset specific. We assume that the errors are independent drawings from a normal distribution with mean zero and constant variance, such that $\epsilon_t \sim \text{NID}(0, \sigma^2)$. We provide extensive specification tests and robustness checks on the NID assumption.

Event study approach is based on comparing realized returns on the event date with normal returns. The normal return, which is an estimate of $\text{E}[r_t|X_t]$, is the predicted

[26] Note that in this case, we would not expect a positive reaction for E.ON: only RWE receives compensation payments, and investors are not concerned about introduction of the uncompensated policy in this scenario, as they have already priced in general unburnable carbon risk.

return given by $\hat{r}_t = X_t\hat{\beta}$. We define the relative time index $\tau = t - T$ to measure the distance to the event date T in terms of trading days. Then, the abnormal returns (AR) are given by $\gamma_{T+\tau} = r_{T+\tau} - \mathrm{E}[r_{T+\tau}|X_{T+\tau}]$, and their estimates are the prediction errors, given by $\hat{\gamma}_{T+\tau} = r_{T+\tau} - \hat{r}_{T+\tau}$.

The null hypothesis that the event does not have an effect over the event window is formulated as H_0: $\sum_{\tau=-h}^{\tau=h} \gamma_{T+\tau} = 0$, where h is the half-width of the event window. Hence, the event window spans the $L = 2h+1$ trading days from $t = T-h$ to $t = T+h$. The sum over the abnormal returns gives the cumulative abnormal return (CAR).

In order to apply the classical t-test, the variance of the CAR can be calculated as $var(CAR) = \iota' V \iota$, where V is the $L \times L$ covariance matrix of abnormal returns and ι is an $L \times 1$ vector of ones. The variance of prediction errors has two components: sampling uncertainity in the estimation of the model parameters and the error uncertainty. If the estimation sample is sufficiently large, one can ignore the sampling uncertainty. Although the sampling uncertainity in our application is small and does not affect any of our results, we do not ignore it. Sampling uncertainty causes serial correlation among abnormal returns. Hence, V has non-zero off-diagonal elements. Its influence is typically very small in short-run event studies, which is the case in our application too. In all our estimations, taking the correlation structure into account does not lead to any visible differences. When the off-diagonal elements are taken as zero, $var(CAR) = \sum_{\tau=-h}^{\tau=h} var(\gamma_{T+\tau})$, where $var(\gamma_{T+\tau})$ is given by $var(\hat{r}_{T+\tau}) + \sigma^2$. The first term is due to sampling uncertainity, and the second term is the error variance.

To interpret the AR as the event effect, the required assumption is that the model is correctly specified such that the predicted returns for the event window are the counterfactual returns to the asset in the absence of the event. The choice of the covariate set is generally motivated by well-known statistical and theoretical models of asset returns. We provide an extensive robustness analysis with respect to this choice. In our baseline estimations, we simply use a constant and returns to a market performance index (the so-called market model), which is generally considered sufficient for short-run event studies (Campbell et al., 1997).

Valid estimation requires that the normal market performance is uncorrelated with the event-induced abnormal returns. To control for potential feedback from the event to the normal market performance, the common approach is to exclude the event window observations in the estimation of expected returns. Given that abnormal returns are simply the prediction errors, the natural choice for the estimation window is to use the observations prior to the event window, potentially leaving a gap between the end of the estimation sample and the beginning of the event window, which we call the "pseudo window". In the absence of any other event, the pseudo-window abnormal returns are expected to be insignificant. We conduct performance tests for the predictive power of our model by calculating L-days CARs for each date in the pseudo window as if an event has occurred on that date.

The most important threat to identification of the event effect is the presence of other contemporaneous shocks in the event window. There are several ways to control for such potential biases. First, when there is a limited number of assets or announcements, it is feasible to review the news around the event dates. We undertake this approach by using a news search engine and we identify a small number of such potential confounding events, which will be discussed in Section 7.2. Second, the event window should be kept reasonably small to rule out other asset-specific events around the event window. Third, the market model can capture the average effect of market-wide shocks via the market price index. However, the market price index is not a proper counterfactual control unit because the event-affected units might participate in this portfolio, leaving the price index endogenous to the event shock. Also, the weights of the market index are not intended to produce a control unit for the affected company, but to reflect the average market conditions. In order to take care of this concern, we apply a synthetic control approach which allows choosing assets to create a counterfactual portfolio and estimating their weights.[27] We provide a detailed description of this approach in Appendix D.

To control for industry-wide shocks, we use EnBW as the control unit, a company

[27] See (Abadie and Gardeazabal, 2003) for the synthetic control estimation. See, for example, Guidolin and La Ferrara (2007) for an application of synthetic control estimation in an event study analysis. An alternative approach might be to use a different market index. This approach is less preferable, since our goal is to capture the common shocks in the market that are most relevant for the subject firms.

in the same industry but without any relevant lignite asset. Therefore, a priori, we do not expect the series of events subject to our analysis to have any effect on EnBW. This gives a difference-in-differences estimate of the abnormal returns by removing biases from industry-wide shocks to returns to asset i.[28] We provide a technical description of this approach in Appendix D.

When there are more than one announcement, testing H_0 amounts to testing the significance of average cumulative abnormal returns (ACAR) over the announcements. Index different announcements with $j = 1, .., J$, and denote the corresponding announcement date with T_j. Therefore, $\tau = 0$ at $t = T_j$ for all j. In these estimations, we use announcement specific estimation windows located at a common distance to the announcement dates. The average abnormal return (AAR) at distance τ is given by $(1/J) \sum_{j=1}^{J} \gamma_{j,T_j+\tau}$, and its variance is given by $(1/J^2) \sum_{j=1}^{J} Var(\gamma_{j,T+\tau})$. The ACAR and its variance can be calculated as described previously by using the AARs and their variances (Campbell et al., 1997).

6 Baseline Results

We employ data on three publicly listed German energy utilities, namely E.ON, RWE, and EnBW. Their stock prices and all other data are from Thomson Reuters Datastream, unless otherwise noted. To calculate market returns, we use the DAX, a performance index consisting of the 30 major German companies trading on the Frankfurt stock exchange. In the estimations presented in the main text, the covariate set includes a constant and the market return, which is generally considered to be sufficient for short-run event studies (Campbell et al., 1997). In the Appendix, we provide robustness tests by also using retuns to oil prices and a risk free rate fo return. These additional covariates do not have any predictive power in our estimations, and hence, their inclusion does not have any effect on the results. We provide a comprehensive description of our dataset and various descriptive statistics in Appendix C. Throughout the paper, the details of a specification,

[28] In terms of the synthetic control approach, this can be considered as assigning a weight of 1 to EnBW and 0 to all other assets in the donor pool.

Table 3: ACARs by the Stages of the Proposal

Companies	Events		
	Climate levy proposal	Security reserve proposal	State aid assessment
RWE	0.012	-0.007	-0.102***
	(0.020)	(0.016)	(0.019)
E.ON	0.011	-0.019	-0.072***
	(0.017)	(0.014)	(0.013)

Notes: This table presents the average cumulative abnormal returns of RWE and E.ON from the announcements of each stage of the policy proposal. The event window is the 5 days centered around an announcement. The estimation window is the 90 days just prior to the event window. Hence, the event window observations are excluded in the estimation of normal market performance. Standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$,** $p < 0.05$, *** $p < 0.01$.

such as window widths, are listed in the table and figure notes.

We start by presenting the average effect of announcements for each stage of the proposal. This strategy applies a strict punishment for the presence of irrelevant announcements. Therefore, rejecting the null requires a strong reaction in the relevant announcements. The results are presented in Table 3, where each entry refers to the ACAR. For both RWE and E.ON, only the effects of the "challenge to the compensation" stage are significant. That is, investors did not react to the initial climate levy proposal, which was directed at stranding lignite assets by charging an extra fee on carbon emissions, and to the following announcements related to the compensation mechanism, that is, paying plant owners for not operating their units. Only the news that the compensation mechanism might not go through due to violating state aid rules seems to have triggered a significant and negative reaction. These results are consistent with Scenario 3 only. That is, investors do price in the stranded asset risk, but with an expectation of a compensation policy.[29]

Inference based on the average CARs reduces the possibility of incorrect rejection of a true null hypothesis (type I error). However, it increases the possibility of failing to reject a false null hypothesis (type II error), which might be responsible for the insignificant results for the first two stages of the policy development. In Table 14 in the Appendix, we

[29] EnBW does not own lignite assets. Our results are in line with this fact. We present the corresponding results for EnBW in the following sections, where we use this company as a control unit.

Table 4: CARs by the Announcements for the State aid Assessments

Companies	Announcements		
	(3a)	(3b)	(3c)
RWE	-0.020	-0.135***	-0.150***
	(0.031)	(0.028)	(0.038)
E.ON	0.004	-0.000	-0.220***
	(0.024)	(0.021)	(0.024)

Notes: This table presents the cumulative abnormal returns of RWE and E.ON from each announcement in the third stage of the policy proposal. The event window is the five days centered around an announcement. The estimation window is the 90 days just prior to the event window. Hence, the event window observations are excluded in the estimation of normal market performance. Standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

provide detailed results based on the CARs for each individual announcement in the first two stages. We show that all the announcements in these stages are still insignificant. Therefore, we conclude that there is no reaction in these two stages. Here, we proceed by investigating the significant effect in Stage 3 in detail.

In Table 4, we present the test results based on individual CARs due to the announcements in Stage 3. The results indicate that the ACARs in stage 3, presented in Table 3, are mainly driven by the CARs during announcements (3b) and (3c): when the media reported on the state aid assessment by Parliament's academic service, and when the EU Commission announced opening the state aid procedure, respectively. Event (3a), the date at which the academic service presented its report to Parliament, seems to have no significant effect on either firm. The insignificant CAR due to this event is in line with our conjecture that this document was not publicly available on that date. Only on the publication dates of the media reports of the assessment do we observe a significant reaction.[30] This pattern is in line with the assumption that investors do not have access to insider information and price in only new information made public via media reports.

The estimated average effect of the announcements related to state aid assessments on RWE is larger, as also illustrated previously in Table 3. This result is in line with the fact that RWE is more lignite-intensive (see Section 2). However, in the next section,

[30]The first report on the assessment was published by *Der Spiegel* (event 3b).

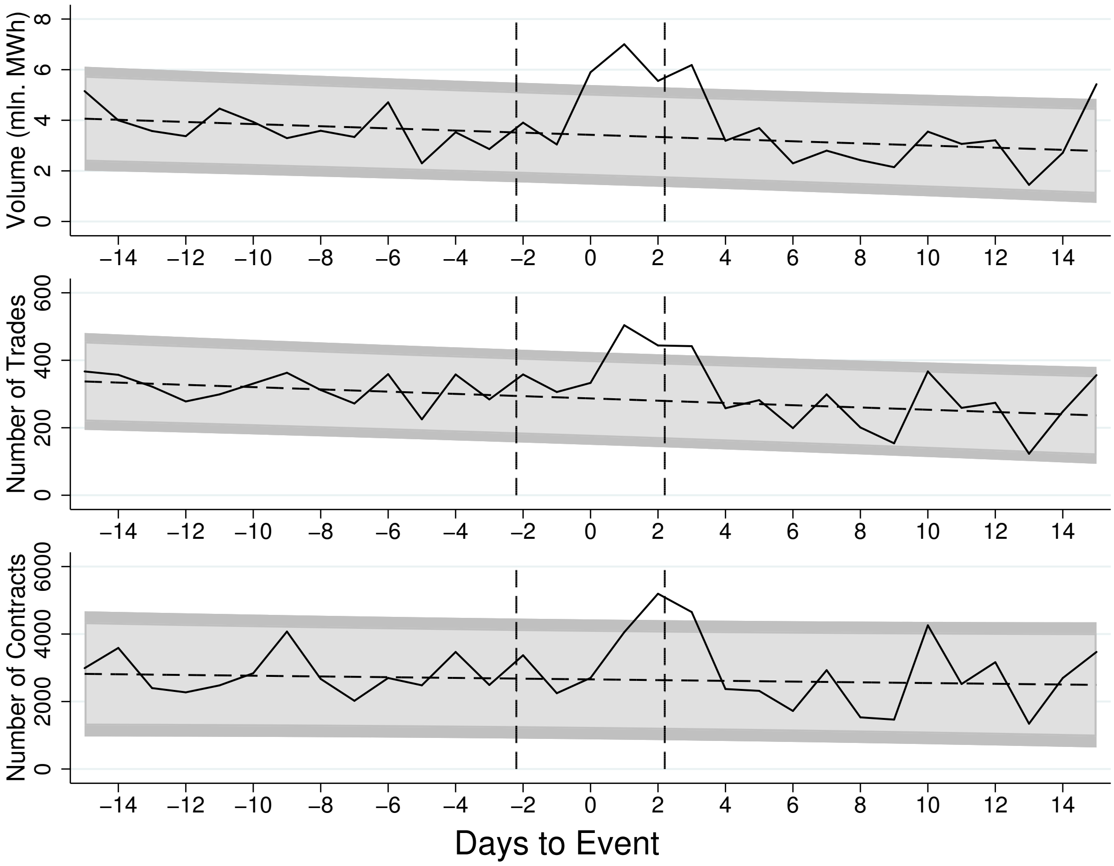
we show that the ARs of RWE due to event (3b) is partially driven by a strong negative earnings surprise, while E.ON is experiencing a small positive earnings surprise. As a result, the difference in the reactions is smaller. Overall, we do not find a significant difference between the reactions across these two firms.

The results presented above show that investors do care about stranded asset risk, but that they also expect a compensation policy for their economic losses. More specifically, investors in stock markets did not react to the announcement of the climate levy proposal, as they expect that the firms involved would not be financially affected. The underlying reason is that, as their reactions to stages 2 and 3 reveals, they expected that the firms would be compensated for their losses.

It is important that such an interpretation would not be possible by interpreting the reactions to individual events independently, as investors' reactions to policy signals depend on their prior expectations. This is the idea underlying our strategy of tracking investors' reactions in the course of the development of a policy proposal. The significant reaction in Stage 3 shows that there is a surprise element in the third stage. In the absence of confounding events, we can conclude that this surprise was due to the challenge to the compensation policy. In the next section, we show that the results from the third stage are not driven by confounding events. Furthermore, this finding explains the underlying reason for our second stage result. Simply, the investors did expect a compensation, and the introduction of a compensation scheme in Stage 2 did not surprise the investors. The result that the investors expect and do care about a compensation scheme explains the absence of reaction to the initial proposal of uncompensated asset stranding in Stage 1. That is, given the findings from Stage 2 and 3, the absence of reaction in the first stage cannot be due to that the investors do not care about a stranded asset risk. In the following, we also provide strong empirical evidence that the initial announcement of the proposal surprised the investors, which also shows that we correctly identified the initial announcement date when new information was released.

To establish surprise for the initial announcement of the proposal, we employ data on future contracts traded at the European Energy Exchange (EEX). Specifically, we

Figure 6: Power-Futures Market around the Announcement of Climate Levy



Notes: This figure illustrates the trading volume, the number of traded contracts, and the number of trades for future contracts traded at the EEX around the first announcement of the policy proposal indicated by date 0. The dashed line is the trend estimated by using the non-event days outside the vertical dashed lines. The shaded regions indicate 90% and 95% confidence intervals based on the forecasts from the estimated trend. The results are robust to various configurations of the estimation sample to estimate the trend.

use EEX futures data for the German power market. The initial proposal implied the stranding of lignite-related assets and meant that significant baseload capacity would not be available after 2016. Therefore, it had the potential to affect activities on the German power futures market. The affected electricity companies themselves would have needed to buy back their positions for the respective delivery period, as they would not have the required capacity any more. Moreover, it is possible that the proposal introduced a general uncertainty among market participants, causing an increased demand for hedging. Both mechanisms would result in increased trading activity – if the proposal came as a surprise to market participants.

Figure 6 illustrates the trading volume, the number of trades, and the number of traded contracts around the first announcement of the climate levy proposal. In all subfigures, we can clearly see an extraordinary increase in market activity starting on the announcement date which persists for a few days. This means that the initial proposal surprised market participants, and they reacted to the implied capacity reduction. However, the stock market did not react to the implied asset stranding (see Table 14 in the Appendix for their reaction to the first announcement). Given our sequential event study results, the natural explanation for this pattern of reactions is that stock market investors believed that the capacity reduction would not mean a financial loss for the affected firms because they expected a compensation.

As a result, the two patterns we observe – the simultaneous, different reactions in the stock and futures markets to the first stage, and the pattern of reactions in the stock market – allow us to conclude that the initial climate levy proposal came as a surprise, but did not change the stock market investors' valuation of the firms as they expect compensation.[31] The significant stock market reaction in stage 3 provides evidence that stock market investors do care about stranded asset risk, and that their insignificant reactions to the first and second stages results from having priced in a compensation policy rather than from ignoring the stranded asset risk. These results are in line with the narrative evidence presented in Section 2.

7 Robustness Analysis

We present the results from alternative modeling choices in the Appendix. First, in Appendix E, we show that our results are robust to using a three-day event window, and employing oil prices and interest rates in the prediction model.[32] Second, we provide extensive specification tests and robustness checks on the assumed error distribution by using both resampling and analytical techniques. These results are presented in Appendix

[31]We conducted the same analysis for the other announcements. There is a similar, but weaker evidence for an increase in power market activity during the second announcement of the first stage, which implies a delayed reaction to the initial announcement of the proposal. In all the other announcements, there is no extraordinary activity. That is, the power markets did not react to the announcements about the compensation plans (Stage 2 and 3), which is in line with basic intuition.

[32]We have verified that our results are robust to using 45, 60, and 120 observations for the estimation sample.

F. In the rest of the paper, we present robustness tests on two other dimensions. In Section 7.1, we focus on analyzing our model's performance in identifying the event effect. In Section 7.2, we investigate whether there are confounding events around the announcement dates that might drive our baseline results.

7.1 Placebo tests and model specification

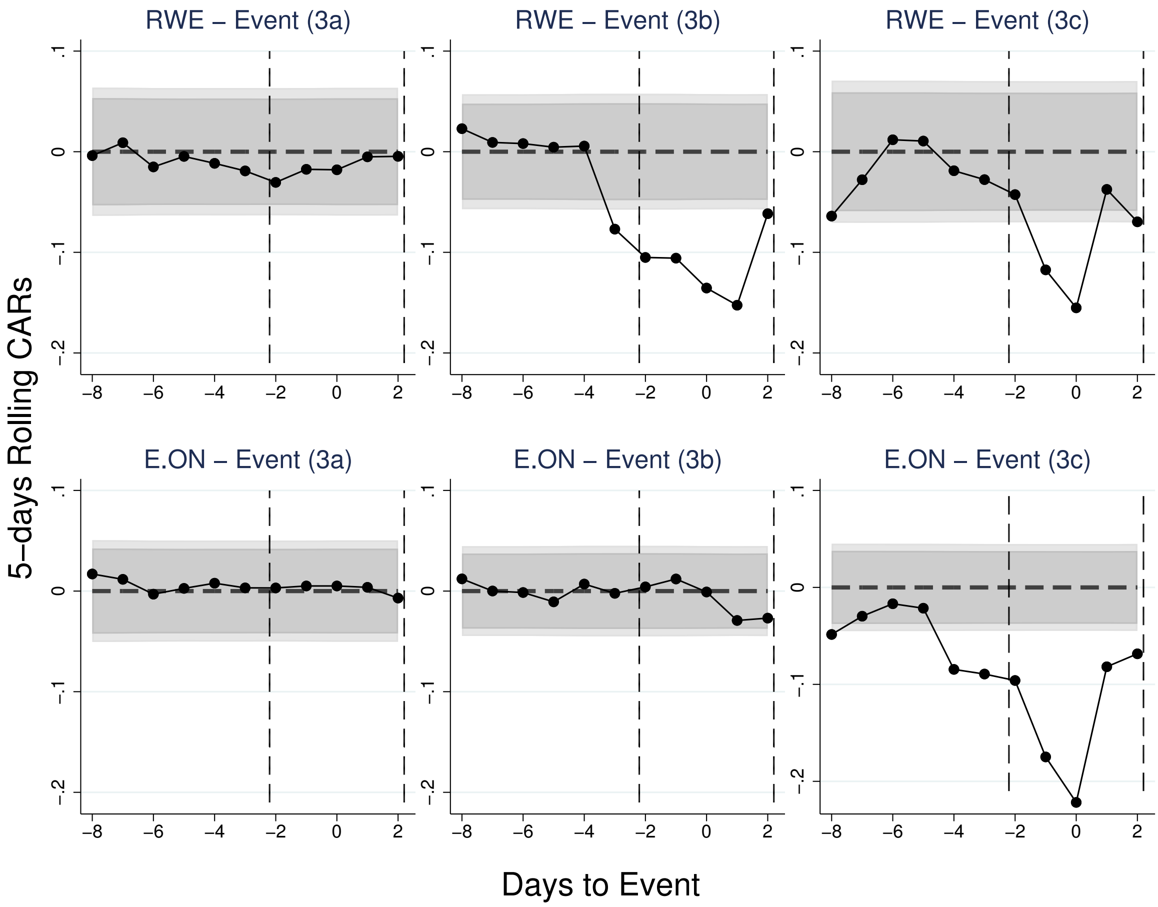
We start by conducting placebo tests by assuming false event windows just prior to our events. This analysis validates our model's performance in predicting the counterfactual returns. Second, we conduct synthetic control estimations to verify that our results are not driven by the endogeneity issue due to the presence of E.ON's and RWE's assets in the DAX30 index.

The results from the placebo tests are presented in Figure 7. On each graph, the left panel separated by the dashed line is the pseudo-event window, and the right panel is the event window. Each point on a graph refers to the CAR calculated from the abnormal returns on the five days centered around that date.[33] The estimated CARs for date zero (the event date) correspond to the results presented in Table 4. The 90% and 95% confidence intervals for the CARs are illustrated as forecast intervals to ease the readability.

Figure 7 shows that the model performs well in predicting the out-of-sample returns in the pseudo window, thus increasing confidence in our model specification. Furthermore, there seems to be no sign of other events in the pseudo windows that bias the estimated CAR around the event day. For the significant events, the CARs are generally stable and insignificant throughout the pseudo window and gradually become negative and significant in the event windows. The gradual change in the CARs and the presence of significant CARs just before the event window is not surprising as we use five-day rolling windows. For example, the calculation of the five-day rolling CAR on date 3, which is in the pseudo window, employs two abnormal returns from the event window. The observed pattern indicates that the event effects seem to be well captured by the five-day event

[33] Corresponding estimated abnormal returns are provided in Figure 24 in the Appendix.

Figure 7: Impact of State Aid Assessments



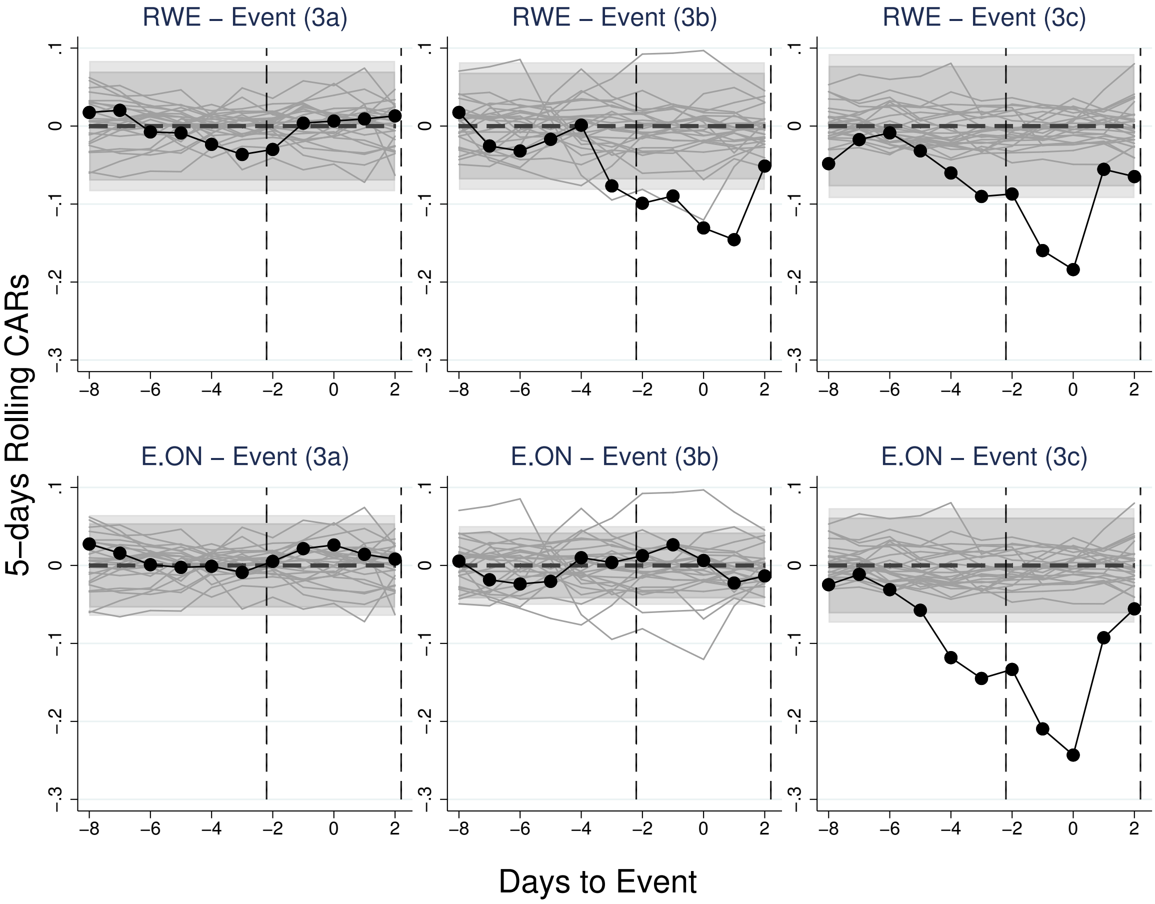
Notes: This figure presents the CARs of E.ON and RWE from each announcement in the third stage of the policy proposal. The event window is the five days centered around an announcement (date 0) indicated with the dashed lines. In the figure, the days prior to the event window are the lacebo announcement days. The estimation window is the 90 days just prior to the pseudo window. Hence, the event window and pseudo window observations are excluded in the estimation of normal market performance. The 90% and 95% confidence intervals are indicated by shaded areas.

window.

To control for potential biases due to the endogeneity of the DAX30 index, we perform synthetic control estimations. Here, we estimate a synthetic portfolio using DAX30 companies by excluding RWE and E.ON. We base the matching procedure only on the asset returns of these companies. The technical details are provided in Appendix D.1. The results are presented in Figure 8.[34] While the qualitative results remain the same, the estimated sizes of the CARs are slightly larger. This indicates that the market price index might have been affected by the events subject to our analysis and therefore absorbed some of the event effects. However, the size of this bias is very small and negligible

[34]See Figure 26 in the Appendix for the corresponding abnormal returns.

Figure 8: Synthetic Control Estimations



Notes: This figure presents the synthetic control estimations of the CARs of E.ON and RWE from each announcement in the third stage of the policy proposal. The event window is the five days centered around an announcement (date 0) indicated with the dashed lines. The days prior to the event window are the placebo announcement days. The estimation window is the 90 days just prior to the pseudo window. Hence, the event window and pseudo window observations are excluded in the estimation of normal market performance. The in-place placebo tests are illustrated with grey lines, and the grey areas are 90% and 95% confidence intervals constructed from the pre-treatment RMSE.

for all the events.

Figure 8 further illustrates some inputs to conduct the non-parametric inference strategy suggested by Abadie et al. (2015) for synthetic control estimations. The so-called "in-place placebo" estimations, which are estimations of the event effect on the units in the control group (donor pool), are illustrated with grey lines. The shaded areas are 90% and 95% prediction intervals constructed from the pre-treatment root mean squared error (RMSE). It is seen that the predicted CARs of untreated units are generally within the prediction intervals which confirms the predictive power of the model.[35] Second, the

[35]The reason underlying the higher dispersion in the in-place placebo CARs around event (3b) will be clarified in the next subsection.

CARs for E.ON and RWE during the event window are extraordinarily higher than the CARs of untreated units. These results are in line with our baseline estimations. We present the non-parametric p-values based on the in-place placebo tests in Table 18 in the Appendix, which are in line with our baseline estimations.

7.2 Confounding events

In this section, we control for the presence of confounding events around the announcement dates that might partially or completely drive our baseline results. To detect confounding events, we used a news search engine and conducted a careful review of the news published around the announcement dates of events (3b) and (3c). The search methodology and a summary of all the results are provided in Appendix G. Our search resulted in two news items.

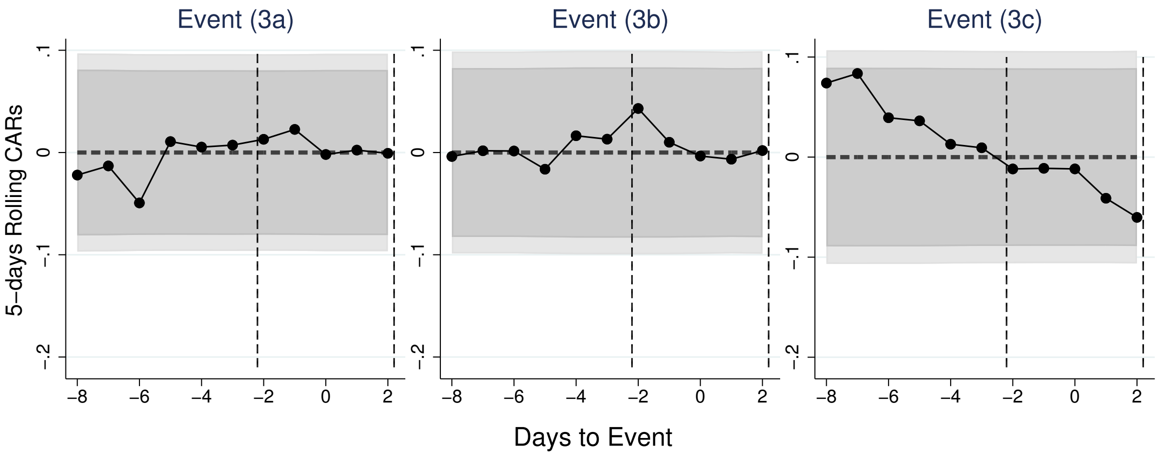
The first item is the *nuclear provisioning assessment* announcement and is potentially relevant for both RWE and E.ON. On September 10, the first trading date in the event window of announcement (3c), the media reported the results of a study commissioned by the Ministry of Economy and Energy.[36] This study concluded that the energy companies' provisioning for liabilities in connection with nuclear plant decommissioning and waste disposal was insufficient. Although this study did not imply direct political or financial consequences, one could imagine that investors reacted to it.

The second item is *earnings announcements*. Both E.ON and RWE published their quarterly earnings announcements just before announcement (3b) - on August 12 and August 13, respectively. Since the announced earnings are company specific, this event has the potential to induce the patterns in the estimated CARs for announcement (3b).

Controlling for the nuclear provisioning assessment In order to control for the nuclear provisioning assessment, we use EnBW, a company from the same industry but without relevant lignite assets, as the single control unit. This strategy leads to

[36] See `http://www.spiegel.de/wirtschaft/unternehmen/atomausstieg-fuer-den-atommuell-fehlen-30-milliarden-euro-a-1052869.html`. For an English-language account of the study and its potential implications for the firms' credit ratings, see `https://www.moodys.com/research/Moodys-Nuclear-shutdown-costs-stress-German-power-generators--PR_335268`.

Figure 9: Pseudo Tests on EnBW



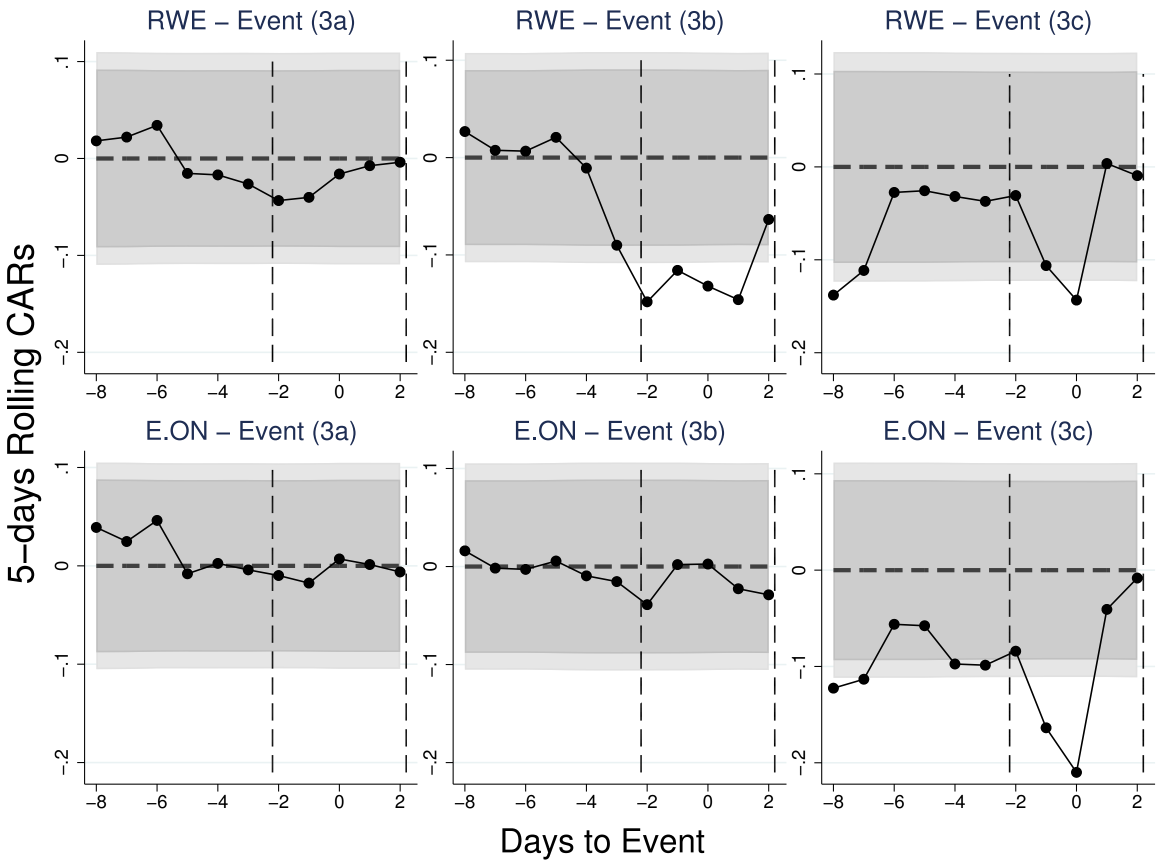
Notes: This figure presents the CARs of EnBW from each announcement in the third stage of the policy proposal. The event window is the five days centered around an announcement (date 0) indicated with the dashed lines. The days prior to the event window are the placebo announcement days. The estimation window is the 90 days just prior to the pseudo window. Hence, the event window and pseudo window observations are excluded in the estimation of normal market performance. The 90% and 95% confidence intervals are indicated by shaded areas.

a difference-in-differences estimation of abnormal returns by removing the effects of common industry-wide shocks (see Appendix D.2 for technical details). The nuclear provisioning assessment can be classified as an industry-wide shock. First, the assessment does not target a specific company, but all companies with nuclear power plants. Second, the problem of nuclear waste is relevant not only for RWE and E.ON, but also for EnBW, which has substantial shares of nuclear energy in its generation portfolio.[37] On the other hand, the lignite policy proposal is irrelevant for EnBW, since it does not hold any asset targeted by the proposal. Therefore, if the nuclear provisioning assessment had any effect, it should be reflected in EnBW's asset returns. By using EnBW as a control unit, we can eliminate the influence of common systematic shocks in a general manner.

This approach requires that (i) the events subject to our analysis had no impact on EnBW's asset returns, and (ii) any systematic difference between the affected units and EnBW can be captured by the set of control variables. To assess the validity of EnBW as a control unit, we investigate the model's performance in predicting EnBW asset returns and check whether there are significant abnormal returns in the event windows. Figure 9

[37]According to the firms' annual reports, 23% of EnBW's installed capacity in 2015 was nuclear power plants, compared to 15% for RWE and 28% for E.ON.

Figure 10: CARs by Using EnBW as a Control Unit



Notes: This figure presents the CARs of E.ON and RWE from each announcement in the third stage of the policy proposal by using EnBW as the control unit. The event window is the five days centered around an announcement (date 0) indicated with the dashed lines. In the figure, the days prior to the event window are the placebo announcement days. The event window and pseudo window observations are excluded in the estimation of normal market performance. The estimation window is the 90 days just prior to the pseudo window. The 90% and 95% confidence intervals are indicated by shaded areas.

presents the results. The CARs stay within the 95% percent confidence intervals both in the pseudo and event windows.[38] This confirms the model's out-of-sample performance in predicting EnBW's returns. Furthermore, these results are generally in line with the assumption that EnBW was not affected by the policy proposals, and reveal that our baseline estimations are not driven by industry-wide shocks such as the nuclear provisioning assessment. If this event had an effect, we would expect to see some reaction in the asset returns of EnBW.

The estimation results from using EnBW as the control unit are presented in Figure 10.[39] Despite being slightly less precise, these estimations are generally in line with their

[38]Corresponding estimated abnormal returns are provided in Figure 24 in the Appendix. See Table 14 in the Appendix for the CARs for each individual announcement.

[39]Other related results are presented in the Appendix: see Figure 27 for the corresponding abnormal

baseline counterparts in Figure 7. The size of the estimated CARs for the event windows is close to those in our baseline estimations, indicating that our results are not driven by some industry-level confounding event such as the report on nuclear waste liabilities (see Table 20 in the Appendix for details).

Controlling for earnings announcements The second news item in our search for confounding events is an earnings announcement (EA) just before announcement (3b). The surprise content of announced earnings are company specific. Therefore, their influence on the estimation results cannot be eliminated by using a control unit. Our strategy to control for the earnings announcement is to correct the CARs on the date of announcement (3b) for predicted abnormal returns due to the earnings surprise.

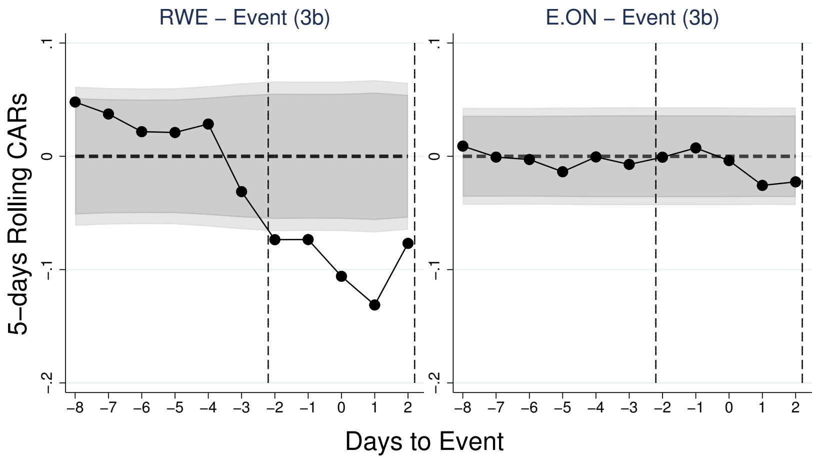
We proxy the expected earnings with the quarterly earnings forecasts reported by the Institutional Brokers Estimate System (I/B/E/S), which is the mean of earnings forecasts by many analysts for a large number of firms. Our measure of surprise is the difference between announced earnings (AE) and mean forecasted earnings (MFE) normalized by the standard deviation of the forecasts, namely, standardized unexpected earnings (SUE) provided by the Thomson Reuters Database.

The technical details of estimating the marginal effect of SUE are provided in Appendix D.3. We provide all the details from each step of these estimations in Appendix H. To summarize, we start by estimating the five-day CARs for all the earnings announcements in our sample by excluding the two earnings announcements by E.ON and RWE just before event (3b). Next, we estimate the marginal effect of SUE on the predicted CARs. Finally, we extrapolate this result to the excluded earnings announcements of RWE and E.ON around event (3b). Finally, we adjust the CARs due to event (3b) with the predicted effect of the earnings announcements.

We repeat pseudo tests on event (3b) (see Figure 7) by taking the predicted effect of the earnings announcement into account. The results are presented in Figure 11, where both the rolling CARs and the prediction intervals are corrected for the size of and uncertainty

returns. The estimation tables by events and by announcements are provided in Tables 19 and 20, respectively.

Figure 11: CARs for Announcement (3b) Corrected for Earnings Surprise



Notes: This figure presents the CARs of E.ON and RWE from announcement (3b) corrected for the effect of earnings announcements. The event window is the five days centered around an announcement (date 0), indicated by the dashed lines. The days prior to the event window are the placebo announcement days. The event window and pseudo window observations are excluded in the estimation of normal market performance. The estimation window is the 90 days just prior to the pseudo window. The 90% and 95% confidence intervals are indicated by shaded areas.

due to the predicted effect of earnings announcements.[40] With a conservative approach, we apply the correction for all the dates presented in the figure. In Appendix H, we provide the corresponding figures illustrating each source of uncertainity separately, and where we assume a five days event window around the date of earnings announcements. In terms of the relative distance to event (3b), the earnings announcement of RWE took place on date -1, while it is date -2 for E.ON. Figure 11 shows that the correction does not have an effect on the results for E.ON. However, the results for RWE changes. The corrected CAR is much smaller compared to the baseline estimate. The corrected effect of event (3b) is still significant against the 95% confidence intervals.[41] These results suggest that the reaction to the state aid assessments is mainly due to announcement (3c).

8 Discussion

Given our results in the previous section, our most conservative point estimate for the 5-days CARs implies a decrease in the market valuation of firms over 20%, which corre-

[40]The corresponding corrected ARs are presented in Figure 28 in the Appendix. See Appendix H for the calculations for the confidence interval.

[41]This is not the case with 99% confidence intervals.

sponds to a 4% average abnormal return over the 5 days around the event. Given RWE's considerable market value (see Table 7 in Appendix C), the monetary impact amounts to around 2 billion Euros. These results show that the investors expect substantial costs from an uncompensated policy, such as the climate levy scenario which became more likely after the compensation for the security-reserve plan faced a legal challenge. This result is in line with our theoretical predictions for RWE in Section 3, that the profit effect of the climate levy scenario can be as high as 18%.

Note that our theoretical predictions are likely to be upper bounds, as allowing for non-constant marginal costs generally reduces the negative profit effects. Therefore, our empirical results imply a slightly higher market reaction compared to the range of theoretical predictions on the rate of change in RWE's profits. The market value of a firm can be seen as a measure of the capitalized risk-adjusted present value of future profit flows. Therefore, the differences can be due to the uncertainty introduced by these announcements. Note that confirming this difference statistically is not possible due to the level of uncertainty surrounding these predictions.

9 Conclusion

We analyze the stock market effects of a German climate policy proposal aimed at stranding fossil assets. We exploit the fact that the proposal underwent three stages. It started as a "climate levy" increasing the CO_2 price for power plants older than 20 years and was subsequently turned into a compensation mechanism paying individual lignite-fired power plants for phasing out. In the third stage, the adoption of the compensation scheme was challenged based on the possibility that it may violate EU state aid rules. We test the effects of news about the different stages of the policy proposal on the German utility companies. We find no significant reactions to the first and second stages, but a significant and negative reaction to the third stage for RWE and E.ON.

Our results suggest that compensation mechanisms are expected and thus priced in the valuation of firms ex-ante. This finding implies that investors do care about stranded asset risk, but because of the expectation of compensation, they do not believe that they will be financially affected - neither by general unburnable carbon risk nor due to specific policy proposals implying the stranding of assets. Only the challenge to the compensation changes their beliefs. Our results imply that the effect of such policy announcements can be substantial. Our most conservative estimates for 5-days CARs imply a loss over 20%.

Stranded asset risk is relevant for the energy sector and beyond. Most fossil energy assets are long-lived; they usually require a large initial investment, but have relatively low operating costs. Davis and Socolow (2014) show that expected future cumulative emissions from the existing infrastructure of the global power sector have increased dramatically in the last decades. Such long-term investments have the potential to "lock in" carbon-intensive technologies for a long period of time (Erickson et al., 2015).[42] Calculations by IEA (2013) and Pfeiffer et al. (2016) conclude that the "2 degree capital stock" will already be reached in 2017. Investments in fossil capacities after 2017 are inefficient: they lead to "both larger carbon lock-ins and higher short-term emissions that need to be compensated by deeper emissions cuts in the long run" (IPCC, 2014), increasing the cost of climate change mitigation. Moreover, in order to achieve emission cuts in such a scenario, fossil assets need to be stranded. IEA (2013) provides a conservative estimate that the energy industry faces sunk costs of \$ 120 billion due to fossil fuel plants being retired early, even if action to achieve the 2°C goal had started in 2012. For a scenario of delaying climate action until 2030 (and using a different methodology), IRENA (2017a) estimates stranded assets of \$ 1.9 trillion in electricity generation, and an additional \$ 7 trillion in upstream energy infrastructure (mostly oil production). This is approximately equivalent to 3.5% of global income, and implies a risk not just for the obviously affected energy industry facing sunk costs: international organizations, financial institutions and regulators are increasingly concerned about the "transition risk" of climate policy, especially about a sudden re-pricing of assets.[43]

[42] Also see Unruh and Carrillo-Hermosilla, 2006; Seto et al., 2016; Unruh, 2000, 2002.

[43] Cf., e.g., European Systemic Risk Board (2016); Caldecott et al. (2016); IRENA (2017b); Batten et al. (2016); Banque de France (2015); Baron and Fischer (2015). Also, see Johnson et al., 2015; Rozenberg et al., 2015; Iyer et al., 2015 for the estimates of long-term energy- and economic-costs of the 2°C goal.

A sudden devaluation of energy companies will occur only if expectations were not adjusted in accordance with the risk of asset stranding. Sudden changes in the stringency of carbon policies, or expectations in the presence of tipping points can lead to abrupt repricing of fossil fuel assets. Given energy companies' size and interrelation with the rest of the economy, policymakers may regard energy companies as "too big to fail." For this and other political economy reasons,[44] policymakers may opt for compensation policies, and investors may expect them to do so. Compensations, then, are almost a self-fulfilling prophecy: if they are expected, they will be necessary in order to avoid larger shocks.[45] Therefore, understanding the interaction between policy making and investors' expectations is essential for the design of climate policies. Our results suggest that early and credible commitment to climate policies and whether they involve compensation payments or not is crucial. Such clear signals to financial markets can avoid a disruptive and unorderly energy transition and macro shocks, while directing capital towards climate-friendly technologies. We believe that further research in similar contexts can help to generalize these results, or to identify the important factors in the formation of expectations regarding climate related risks.

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[44] See Jenkins (2014); Manley et al. (2016); Healy and Barry (2017); Caldecott et al. (2017) for an overview of political economy constraints on climate policy.

[45] Batten et al. (2016) use a similar argument referring to the potential time inconsistency of government policies in the context of stranded assets. They do not consider compensations, however, but only distinguish between a "low carbon equilibrium" and a "high carbon equilibrium."

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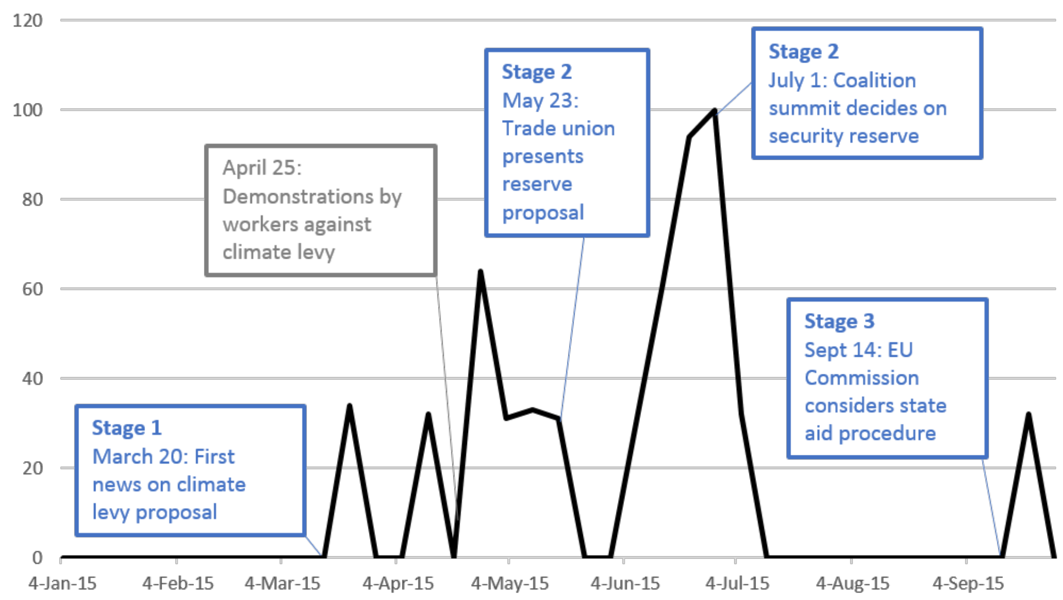
Appendix

A Google Trends Statistics

Figure 12 shows the google trends statistics for the term "Klimabeitrag" (climate levy) between January and September 2015. Google trends report relative frequencies of searches (not absolute search numbers) in weekly intervals. We highlight some of the announcement dates we identified. We also included information on demonstrations against the climate levy as this helps explain some spikes in searches.[46]

Figure 12: Google Trends Statistics for the term "Klimabeitrag" in Germany



We restricted our search to the term "Klimabeitrag" because this is the only term related to the proposal development with a unique meaning. For example, the official term "security reserve" was often replaced by other terms such as "capacity reserve", "lignite compromise" or "climate reserve" in the media, making it difficult to follow the trends in the public interest.

[46] For the demonstrations against (and also for) the climate levy proposal, see e.g. https://www.tagesspiegel.de/wirtschaft/streit-um-zukunft-der-kohle-tausende-demonstrieren-gegen-und-fuer-die-braunkohle/11689424.html.

Table 5: Summary statistics for the data on electricity market

	N	Mean	Median	St. Dev.	Min.	Max.
Total load (GW)	8760	59.46	59.03	10.56	36.15	79.89
Renewable generation (GW)	8760	12.83	11.26	8.54	0.34	42.47
Residual load (GW)	8760	46.63	46.48	11.75	9.39	78.50
Price (Euro/MWh)	8759	31.63	30.54	12.66	-79.94	99.77

Notes: This table presents a set of summary statistics for our main variables based on the raw 2015 electricity market data for Germany.

B More on the theoretical analysis

In this section, we provide further details about the theoretical analysis in Section 3.

B.1 Electricity market data

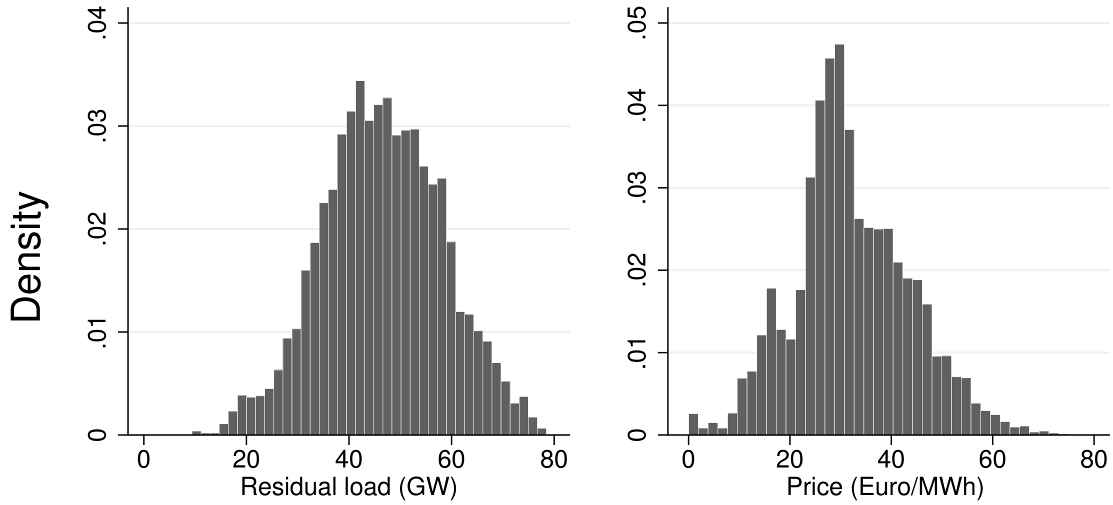
We obtain data on total load, renewable generation, and day ahead prices at the EEX for German power market at hourly resolution from Open Energy Modeling Initiative (OEMI, 2019). We calculate the residual load as total load minus renewable electricity generation. Table 5 presents a set of summary statistics for our main variables based on the raw 2015 electricity market data for Germany. Figure 13 illustrates the distribution of hourly electricity demand and prices, where we only exclude negative prices. In our analysis, we truncate the prices at the upper and lower 2$^{\text{nd}}$ percentiles which drops negative prices as well.

B.2 Capacity utilization

In order to conduct our scenario analysis, we have to rank alternative technologies based on their marginal costs. Our ranking is based on the IEA's cost projections. We depict the implication of this strategy in Figure 14, which shows the technological capacity ranges once more, but together with the merit order curve and the residual load distribution. In order to verify this strategy, we also illustrate the distribution of hourly average power generation by technology in Figure 15.[47] Comparing these two figures verifies the imposed merit order of technologies as follows: The distribution for nuclear is left-tailed, and the

[47] We obtain these data from ENTSOE Transparency Data Platform.

Figure 13: Electricity prices and residual load in Germany in 2015



Notes: This figure illustrates the density of hourly residual load over 2015 and the day ahead prices in the EEX market. The residual load is given by total load minus generated electricity from renewables.

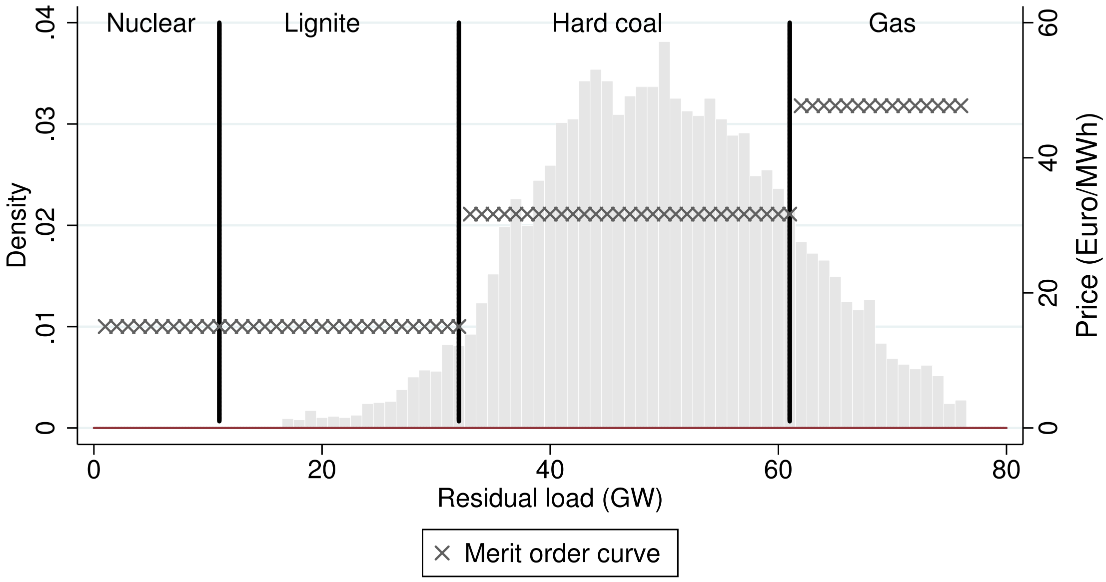
mass is close to its full capacity. This evidence confirms that the nuclear capacity is rarely a marginal technology, but often the infra-marginal technology. The picture for the gas capacity is just the opposite, verifying that it is the marginal technology only at the high load instants.

One can verify the merit order of other technologies with the same reasoning: when the distribution is more left skewed and the capacity utilization is higher, then this technology must have priority in serving to the market. The distribution for the lignite is less left-skewed compared to that of nuclear, and it works at the full capacity less often. Finally, the power generation from hard coal has a quite symmetric distribution which is in line with its merit order rank and its location at the center of the residual load distribution. Hence, this evidence confirms that the marginal technology is generally hard coal.

B.3 The capacities affected by the policies

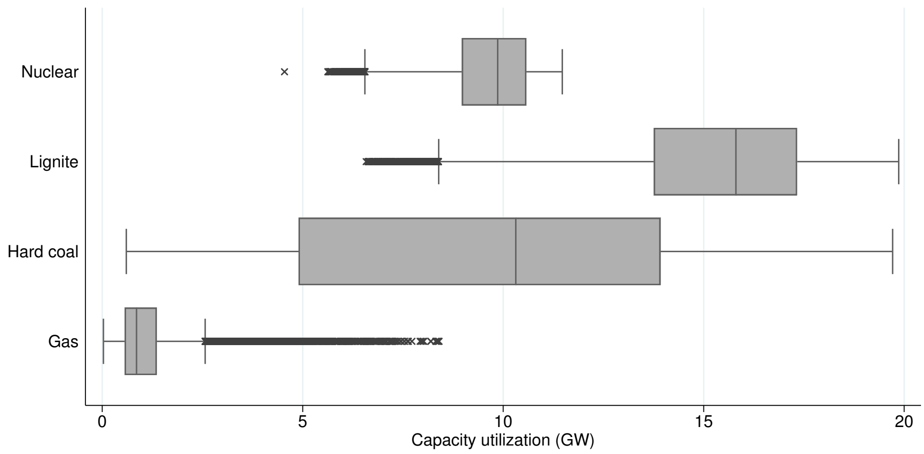
Table 6 presents the list of units to be transferred into the security reserve. This list includes five units of RWE. There are two more firms operating with lignite: Vattenfall GmbH and Mibrag GmbH. However, they are not publicly listed companies, hence not

Figure 14: Density of residual load and the merit order



Notes: This figure illustrates the density of daily residual load in 2015 by technology and the merit order curve used in our scenario analyses. The residual load is given by total load minus generated electricity from renewables.

Figure 15: Distribution of power generation by technology



Notes: This figure illustrates the distribution of average daily power generation in 2015 by technology. The boxes illustrate the quartiles. Capped lines indicate adjacent values (1.5 times the interquartile range away from the upper and lower quartiles). Outliers are marked with cross.

Table 6: Phase-out Schedule

Operator	Name of unit	Nameplate capacity	Mothballing	Decommissioning
Mibrag	Buschhaus	352 MW	Oct 1, 2016	Sep 30, 2020
RWE	Frimmersdorf P	284 MW	Oct 1, 2017	Sep 30, 2021
	Frimmersdorf Q	278 MW	Oct 1, 2017	Sep 30, 2021
	Niederaußem E	295 MW	Oct 1, 2018	Sep 30, 2022
	Niederaußem F	299 MW	Oct 1, 2018	Sep 30, 2022
	Neurath C	292 MW	Oct 1, 2019	Sep 30, 2023
Vattenfall	Jänschwalde F	465 MW	Oct 1, 2018	Sep 30, 2022
	Jänschwalde E	465 MW	Oct 1, 2019	Sep 30, 2023

Source: State Aid Decision Text (SA.42536), Closure of German Lignite Plants: Letter to the Member State. Available at `http://ec.europa.eu/competition/state_aid/cases/261321/261321_1762503_157_2.pdf`.

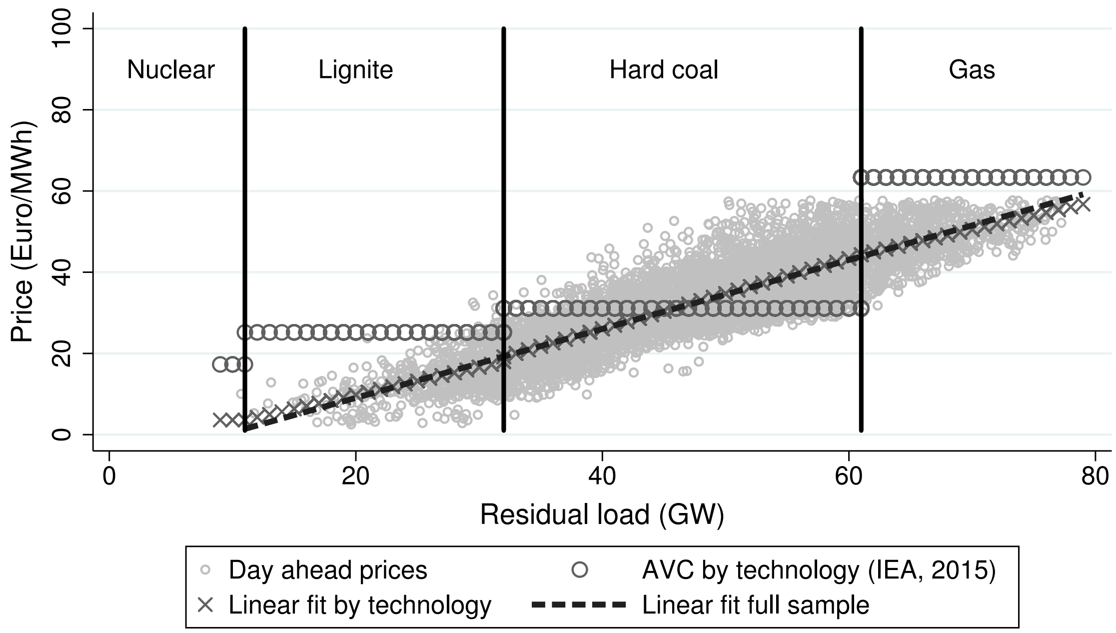
relevant for the event study analysis.

B.4 Non-constant marginal costs

In order to illustrate the overall profit effect of using a non-constant supply curve, we provide a naive estimate for the merit order curve. In Figure 16, we display our linear predictions per technology, where we estimate the supply curve separately for each capacity range determined by the merit order of different technologies. It is seen that the technology-specific fit is very close to the fitted line to the full sample. In the rest of the section, we use these technology-specific linear estimations.

Figure 17 shows the effect of the climate levy on the supply curve, where the technological capacities are illustrated for the baseline situation prior to the arrival of the policy shock. We assume that the policies affect the lignite capacities with the highest marginal cost of electricity production. The supply curve of the hard coal capacity shifts to left, and the affected lignite capacity is relocated just to the left of the gas capacity. Hence, the location of the gas capacity does not change in this scenario. Note that this is not the case in the security reserve scenario, where we simply remove the affected lignite capacity from the supply schedule. We do not present the same figure for the security

Figure 16: Technology specific linear fits



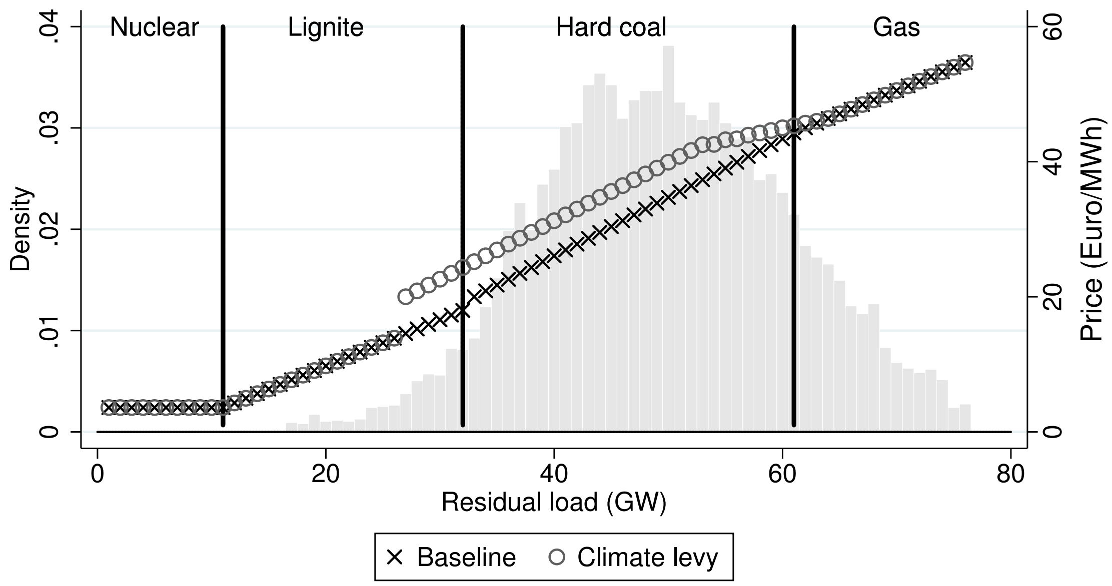
Notes: This figure illustrates the price and residual load observations, the linear fits per technology, the linear fit to the full sample, and the IEA's cost projections. The prices are day-ahead prices in the EEX market in 2015. The residual load is given by total load minus electricity generation from renewables.

reserve scenario for brevity. However, we illustrate the price and profit effects for both scenarios in the following analyses.

The predicted changes in prices are illustrated in Figure 18 for both the climate levy and the security reserve scenarios. This figure highlights several important points. First, there is no shift in the supply curve for the nuclear and unaffected lignite capacities. Therefore, the prices do not change. Second, the location of the gas capacity changes in the security reserve scenario, but not in the climate levy scenario. As a result, the prices at the high-load instants do not change due to the climate levy. Third, the price increase is constant in residual load for the capacity ranges where there is only a shift in the supply curve. However, the price changes can be increasing or decreasing in residual load depending on the change in the slope of the supply curve. Since we assumed linearity, the slope of the supply curve changes only at the capacity ranges where the production technology changes.

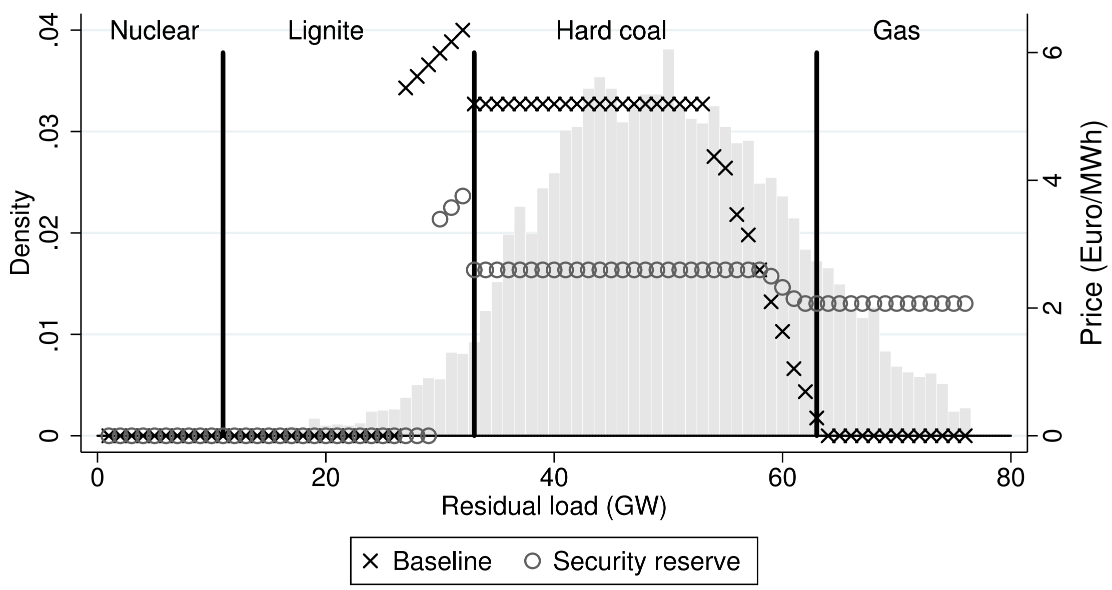
Figure 19 presents the profit effects by using the estimated technology-specific linear merit order curve. The results are as follows: First, there is no change in the profits when

Figure 17: Climate levy and the supply curve



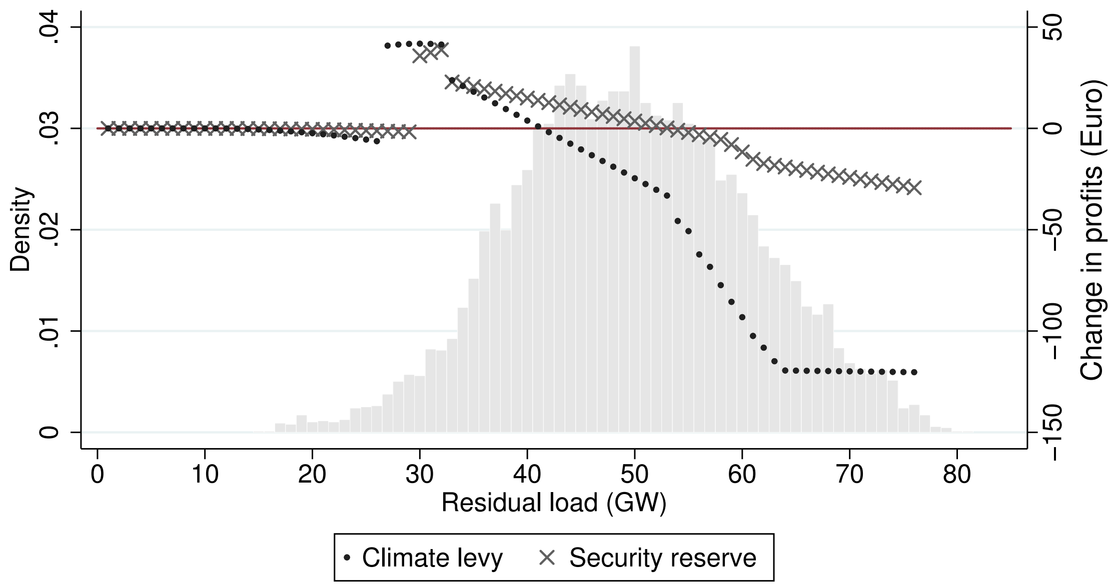
Notes: This figure illustrates the changes in the supply curve for the climate levy scenario. The residual load is given by total load minus generated electricity from renewables.

Figure 18: Changes in prices



Notes: This figure illustrates the predicted changes in prices for the climate levy and the security reserve scenarios. The residual load is given by total load minus generated electricity from renewables.

Figure 19: Changes in profits



Notes: This figure illustrates the predicted changes in profits at each load instant for the climate levy and the security reserve scenarios. The residual load is given by total load minus generated electricity from renewables.

the marginal technology is nuclear, as there is no change in prices. Second, there is a minor and negative profit effect at the hours when the unaffected lignite capacity is the marginal technology, although there is no price change at those hours. The reason is that the policy scenarios change the RWE's share in the unaffected lignite capacity. Third, there is a strong jump in prices at the load instants where the lignite capacity is replaced with hard coal capacity. This jump results in extra profits from the infra-marginal nuclear and unaffected lignite capacity. The profit effects are increasing in residual load within this capacity range, because the hard coal replacing lignite capacity has a steeper supply curve. Fourth, at the average load instant where the hard coal capacity is operating, the increase in price leads to positive profit effects for the infra-marginal nuclear and unaffected lignite capacity. On the other hand, the hard coal capacity operating at the average load is now producing with higher marginal costs, which exerts a negative pressure on the profits. The net effect is generally positive to the left of the average load and generally negative to the right. The reason is that, the share of capacity operating with higher marginal cost is higher to the right of the average load instant. Therefore, the profit effects become gradually negative at higher load instants.

We calculate the overall profit effects as the average of the profit changes weighted with the residual load densities. Overall, we find that the climate levy causes 11% profit loss on average. For the security reserve scenario, even without any compensation, our results indicate that there is no change in profits on average (0.06% increase). This result shows that allowing for non-constant marginal costs tends to reduce the negative profit effects compared to our baseline assumption of constant marginal cost.

We conclude this section with some final remarks. The predicted price changes in this section are quite high. Around the average load, the climate levy leads to a more than 5 Euros increase in the equilibrium price, and the security reserve scenario causes an increase around 2.5 Euros. As a result the market equilibrium occurs at a higher price, which has a strong positive profit effect on each capacity unit operating at an average load instant, in particular for infra-marginal nuclear and unaffected lignite capacities. These predictions for price changes are much higher than those in Oei et al. (2015), where the predicted price increase is minor. The explanation might be that our naive estimate of the slope can be upward biased for several reasons. One problem might be the linearity assumption. Note that the estimated technology-specific lines form a quite smooth merit order curve. This result may be at odds with its common illustration with discrete jumps due to the presence of different production technologies in the supply schedule. In addition, one might expect its slope to be lower at lower load instants and higher at higher load instants. However, we have verified our estimations by conducting nonparametric robustness checks. A more likely problem is the simultaneity bias in the estimations of reduced-form supply or demand functions. Identifying the supply curve from data on equilibrium outcomes requires the demand to be fully inelastic. This might be an extreme assumption at the hourly resolution, as consumers might have a certain degree of flexibility in shifting their activity to different hours in a day (Mier and Weissbart, 2019).

Table 7: Descriptive Statistics

	Units	Mean	Median	St. Dev.	Min.	Max.	Obs.
Stock price - RWE	€	18.392	19.789	5.330	9.219	25.684	261
Stock price - E.ON	€	10.253	10.853	1.957	6.331	12.889	261
Stock price - EnBW	€	24.120	24.800	1.660	19.866	26.759	261
Market value - RWE	bln. €	10.589	11.393	3.069	5.308	14.787	261
Market value - E.ON	bln. €	23.388	24.758	4.464	14.441	29.403	261
Market value - EnBW	bln. €	6.672	6.860	0.459	5.495	7.402	261
Risk free rate	%	-0.001	-0.001	0.000	-0.002	-0.000	261
Returns to DAX30 price index	%	0.035	0.063	1.460	-4.816	4.852	261
Returns to oil price	%	-0.188	0.000	2.346	-12.452	15.537	261

Notes: All values are based on 2015 data. Market value is equal to daily stock price times number of outstanding shares.

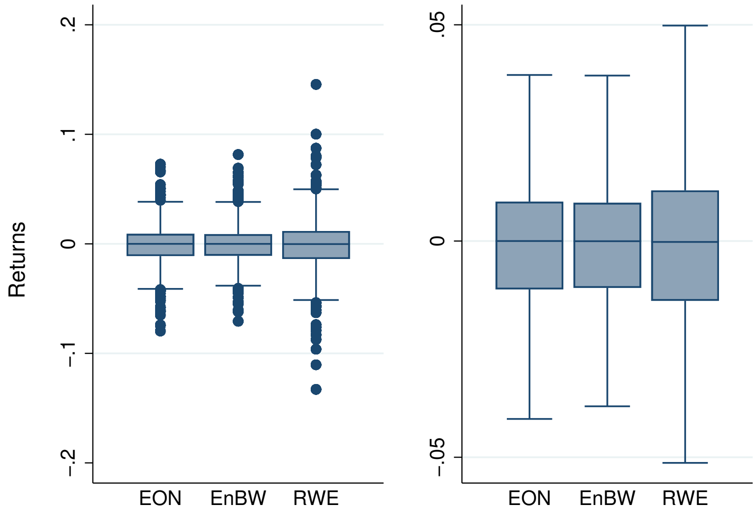
C Data and Descriptive Statistics

Our dataset is mainly from the Thomson Reuters Datastream. The market return is based on the DAX, a performance index consisting of the 30 major German companies trading on the Frankfurt stock exchange. The continuously compounded returns are first differences of logarithm of prices. The descriptive statistics for the stock prices and market value of the three utility firms, and the returns to DAX30 index are provided in Table 7. Figure 20 illustrates the distribution of the returns for all three companies. The right panel excludes outliers to ease comparison around the center of the distribution.

In the Appendix, we provide robustness tests by using oil prices and interest rates. Their inclusion does not have any effect on the results. We use the crude oil spot price of Brent, FOB, and the German three-month government bond benchmark rate as the risk-free rate of return. The summary statistics for these additional variables are provided in Table 7 along with our main variables. The level of and the variation in the interest rates are very low throughout 2015. The returns to oil prices is characterized by many outliers. As a result these variables do not add much to the explanatory power of the market model.

In using EnBW as a control unit, one concern might be that the results for EnBW are driven by a company-specific characteristic that makes its assets immune to any type

Figure 20: Distribution of the Returns



Notes: This figure illustrates the distribution of the returns for all three companies. The dots indicate outliers. The right panel excludes outliers.

of shock. In this case, using EnBW as a control unit would not eliminate the influence of a potential industry-wide shock. In Figure 20 it is clear that the distributions of returns are more or less the same both at the tails and at the center. Therefore, it is not likely that the results for EnBW are driven by a company-specific characteristic. Hence, using EnBW as a control unit seems a sensible strategy.

D Details on Estimation Strategies

Our baseline estimation strategy is a short-run event study analysis. However, we use several specifications and identification strategies. To lay out our assumptions about the identification of an event effect and to facilitate comparison among alternative estimators and specifications, this section adopts a regression-based exposition of the short-run event study approach, while we also explain how it is related to the classical exposition in the main text.[48]

Consider the following specification to assess the impact of a single event at date T

[48] The short run event study methodology was introduced by Fama et al. (1969). See MacKinlay (1997) for a detailed description. The regression-based exposition is an alternative that is widely used in the literature. See, for example, Binder (1985a,b).

on the returns of a single asset i:

$$r_{it} = X_{it}\beta_i + \sum_{d=-h}^{+h} \gamma_i^d D_t^d + \epsilon_{it}, \tag{1}$$

Almost all the elements of this specification has been introduced in the main text: r_{it} is the continuously compounded return of the asset at the trading date t, X_{it} is the vector of covariates predicting the normal performance, and h is the half-width of the event window. We ignore the pseudo window for brevity. The potential effect of the event on the returns is captured by the set of event day dummies, $D_t^d = 1\{\tau = d\}$, where $d = -h, -h+1, .., h$ and the relative time index τ measures the distance to the event. Since the coefficient vectors, β_i and γ_i^d, and the error term, ϵ_{it}, are asset specific, Equation (1) is asset specific.

In this specification, as the event day dummies capture the whole variation in the event window, the event window observations are not relevant for the estimation of normal returns.[49] As a result, this specification is equivalent to the approach described in the main text: the event related abnormal return is given by $\gamma_i^d = r_{i,T+d} - \mathrm{E}[r_{i,T+d}|X_{i,T+d}]$, and its estimate is the prediction error, given by $\hat{\gamma}_i^d = r_{i,T+d} - \hat{r}_{i,T+d}$. The null hypothesis that the event does not have an effect over the event window is formulated as:

$$H_0\colon \sum_{d=-h}^{h} \gamma_i^d = 0.$$

To account for many announcements, the second term of Equation (1) can be extended to all announcements. This is the approach described in Binder (1985a). The event day dummies are modified as $D_t^d = 1\{d = \tau \text{ for all } j\}$, where T_j denotes the date of announcement j. For example, $D^{-1} = 1$ when $\tau = t - T_j = -1$, which is the case for

[49]Equation (1) excludes the event window observation in the estimation of expected returns as explained earlier. The pseudo window can be introduced as follows:

$$r_{it} = X_{it}\beta_i + \sum_{d=-k^u}^{-h-1} \gamma_i^d D_t^d + \sum_{d=-h}^{h} \gamma_i^d D_t^d + \epsilon_{it}, \tag{2}$$

where the chosen relative distance to the announcement date is k^u such that $k^u > h$. The abnormal returns between $T - k^u$ and $T - h$ are expected to be insignificant, and can be used to conduct pseudo tests.

all dates one day prior to any announcement date. The average abnormal return (AAR) can be estimated by using Equation (1), but with redefined event day dummies.

$$r_{it} = X_{it}\beta_i + \sum_{d=-h}^{h} \gamma_i^d D_t^d + \epsilon_{it}. \quad (3)$$

In this case, each event day dummy captures the AAR across announcements for a day in the event window. Therefore, testing H_0 amounts to testing the significance of the average of cumulative abnormal returns (ACAR) over the events. To utilize variation across firms, one can simply impose $\gamma_i^d = \gamma^d$ and/or $\beta_i = \beta$.

In all our estimations, we allow the parameter vector β to be not only firm but also announcement specific. That is, in order to predict the counterfactual returns for each announcement, we employ a different sample around each announcement, and estimate β separately. This is equivalent to using Equations (1) or (2) to estimate the CARs and calculating the ACAR subsequently, as described in the main text. This approach can be represented by a regression model as follows:

$$r_{ijt} = X_{ijt}\beta_{ij} + \sum_{d=-h}^{h} \gamma_i^d D_t^d + \epsilon_{ijt}, \quad (4)$$

where j is the announcement index.[50]

In a single asset - single event case, there is only one observation for each date in the event window, hence the estimated abnormal returns are simply prediction errors. This is the case for Equation (1) as it represents a separate regression for each firm and announcement. When there are repeated observations for the event, in the form of many announcements or assets, and if the specification includes common event day dummies across announcements or assets as in Equations (3) and (4), then the estimation utilizes some of the variation in the event window in the calculation of expected returns. In the following discussion, we use common event day dummies for the sake of clarity and

[50]Note the unusual indexation of the observations in this specification. Normally, the asset return, covariates, and error term should be uniquely defined by i and t. Indeed, if the normal market performance is estimated from a common sample of firm i's returns for all announcements, one can drop the j index. However, we allow the market structure to differ around announcements. In this case, the effective time index is τ, which is uniquely identified by j and t. Similarly, each i and j combination can be considered as a separate cross-sectional unit.

brevity. However, this is not our approach in practice: we implement all our abnormal returns estimations as described in the main text by excluding the event windows, and apply aggregation over assets or announcement expost. The equivalent regression-based approach would be to define separate dummies for each event day observation identified by (i, j, t). However, if the estimation windows are much larger than the event windows, then both approaches lead to similar results. In our case, the differences are ignorable.

D.1 Endogeneity of the market price index

Given the limited number of observations for the event effect, applying a synthetic control approach (Abadie and Gardeazabal, 2003) is an obvious, yet rarely pursued strategy in short-run event studies. Its main requirement is to have sufficient observations in the pre-event sample to form a control unit. Extrapolating the outcome variable of the control unit to the event period and comparing it with the observed outcome of the affected units is the same idea underlying both the short-run event study approach and the synthetic control approach.

Note that Equation (1) can be reformulated as a synthetic control estimation where $X_{it}\hat{\beta}_i$ can be considered the predicted outcome of the control unit. Then, the event effect is tested on the difference between the observed outcome at the event date, r_{iT}, and the extrapolated control outcome to the event date, $X_{iT}\hat{\beta}_{i|T-h-1}$. Indeed, the usual control variable in X_{it}, the market index, is already a weighted average of asset prices in a given market. The problem is that the event-affected units might participate in this portfolio, and the weights do not aim to produce a proper counterfactual control unit for the affected company, rather to reflect the average market conditions. The synthetic control approach allows to choose assets to form a counterfactual portfolio and to estimate their weights.

Let $i = 1$ be the company that is hypothesized to be affected by the event. A synthetic control is a weighted average of the units in the so-called donor pool of I units unaffected by the event. Each choice of the vector of weights $W = (w_2, ..., w_{I+1})$ such that $0 \leq w_i \leq 1$ and $w_2 + \cdots + w_{I+1} = 1$ refers to a particular synthetic control. This choice is based on the pre-event characteristics $Z_{i,t<T-k} = \bar{Z}_{it}$. Potentially, one can include the outcome

variable as a potential characteristic. That is, we have $\bar{Z}_{it} = [\bar{r}_{it}, \bar{X}_{it}]$. Indeed, Abadie et al. (2010) argue that matching on pre-event values of outcome variables mitigates the concerns related to unobserved factors in $\bar{Z}_{it}$. Weights can be chosen with the following criteria

$$w_i^* = \arg\min_{w_i} \sum_i v \left(\bar{Z}_1 - \bar{Z}_{i\in I}\right)^2 \text{ st. } 0 \leq w_i \leq 1,\; w_2 + ... + w_{I+1} = 1, \tag{5}$$

where v is a vector of variable-specific weights. For example, in Equation (1), the parameter vector β can be considered a special form of v. The synthetic control estimation of abnormal returns is then given by

$$\gamma_{1t}^d = r_{1t} - \sum_{i\in I} w_i^* r_{it}, \text{ for } t \in [T-h, T+h].$$

We calculate the cumulative abnormal returns as the sum of abnormal returns. In estimating a synthetic portfolio, we use DAX30 companies by excluding RWE and E.ON. We base the matching procedure only on the asset returns of these companies.

D.2 Controlling for industry-wide shocks

We use EnBW as the control unit, a company in the same industry but without any relevant lignite asset. This gives a difference-in-differences estimate of the abnormal returns by removing biases from industry-wide shocks. To see this formally, let $i = 1$ denote the company that is hypothesized to be affected by the event, and $i = 2$ denote the control unit. Let the dummy variable $C_i = 1\{i = 1\}$ indicate the treatment group. We have the following specification:

$$r_{it} = X_{it}\beta_i + \sum_{d=-h}^{h} \delta^d D_t^d + \sum_{d=-h}^{h} \gamma^d D_t^d C_i + \epsilon_{it}. \tag{6}$$

Note that the asset specific intercepts are already included in the parameter vector β to control for differences between the two cross-sectional units over the estimation window. The second term captures the shocks that affect both units. Then $\hat{\gamma}^d$ is the estimated average event effect on firm 1 on an event window day d.

D.3 Other Specifications

Intensity of the event. In some applications, there is a continuous variable measuring the intensity of the potential event. For example, in one of our robustness analyses, we investigate the effect of a confounding event: in this case, an earnings announcement. In this analysis, the surprise in the earnings announcement is a continuous variable and if the announcement has any effect, it is expected to be correlated with the magnitude of the surprise. Having repeated observations for the event effect allows estimating the marginal abnormal returns due to the surprise.

Denote the intensity of the surprise with s_{ij}. Then, Equation (4) can be modified as follows:

$$r_{ijt} = X_{ijt}\beta_{ij} + \sum_{d=-h}^{h} \gamma_i^d D_t^d s_{ij} + \epsilon_{ijt}. \tag{7}$$

Here γ_i^d is the marginal effect of the surprise. The abnormal return of firm i due to announcement j is calculated as $\gamma_i^d s_{ij}$.

Estimation window with repeated observations for the event effect. As explained earlier, the specification in Equation (1) does not employ any information from the event window to estimate the expected returns. This strategy can control for potential feedbacks from the event to the normal market performance. However, this is not the case for Equations (4) and (7), because the event dummies are assumed to be homogeneous across announcements (or firms) and do not partial out the whole variation in the event window. Hence, one has to include a dummy for each observational unit in the event window.

We take care of the feedback from the events to the normal market performance by estimating the normal market performance separately from the pre-event observations. The return on a day in the event window is predicted by $\hat{r}_{i,T+d} = \mathrm{E}[r_{i,T+d}|X_{i,T+d}] = X_{ij,T+d}\hat{\beta}_{ij|T-h-1}$, where the estimated parameter vector is conditioned on the available information prior to the event window. The abnormal return is then given by:

$$\gamma_{ij}^{d} = r_{i,T+d} - X_{ij,T+d}\hat{\beta}_{ij|T-h-1}. \tag{8}$$

As a result, the prediction of the expected returns does not employ any information from the event window. In this case, the intensity of the event effect is estimated in a second-stage regression by regressing the estimated CARs on the surprise (see MacKinlay, 1997). In all our applications, we exclude the event window observations in estimating the normal market performance.

E Robustness Checks on the Choices for Baseline Specification

In this section, we present the results from alternative choices for the event window and covariate set. In Table 8, we present the results from assuming three-days event windows instead of five days. These estimations correspond to our baseline estimations leading to Table 3 where we assume five-days event windows. As the ACARs in Table 8 are based on three days ARs, the size of the coefficients is smaller compared to their baseline counterparts also by construction. It is seen that assuming a three-days event window does not alter the significance levels. We are therefore confident that our baseline specification of five days does well in capturing the full event effects. In the Appendix for further tables and figures (Appendix I), we present the corresponding results from announcement specific estimations in Table 15 which corresponds to the announcement-specific baseline estimations in Table 14.

In the main text, we do not find any significant market reaction to Event (1a). However, we provide empirical evidence that it was still surprising. In order to verify that the insignificance of CARs from Event (1a) is not driven by our event-window specification, we present the abnormal returns around this event in Figure 25. It is clear that any meaningful combination of these abnormal returns cannot lead to significant CARs.

Table 8: ACARs by the Stages of the Proposal: Three-days Event Window

Companies	Stages of the proposal		
	Climate levy proposal	Security reserve proposal	State aid assessment
RWE	0.007	0.003	-0.063***
	(0.016)	(0.012)	(0.015)
E.ON	0.009	-0.009	-0.034***
	(0.013)	(0.010)	(0.011)

Notes: This table illustrates the average cumulative abnormal returns of E.ON and RWE from the announcements of each stage of the policy proposal. The event window is the three days centered around an announcement. The event window observations are excluded in the estimation of normal market performance. The estimation window is the 90 days just prior to the event window. Standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Some of our event dates are very close. This is not a problem for the events in Stages 1 and 2, as there are no abnormal patterns in the returns around these dates. However, the estimation window of Event (3c) includes the event window of Event (3b). Therefore, the significant abnormal returns due to Event (3b) might have consequences on the estimated normal market performance of Event (3c). In order to address such concerns, we provide robustness chekcs by estimating the normal market performance by using the 60 days window which ends at 30 trading days before the event window. The results are presented in Table 16 in the Appendix for further tables and figures. It is seen that our results for Event (3c) are not driven by this concern. As a further specification test on the choice of estimation windows, Table 16 presents this robustness check for all the other events as well. The results are similar to our baseline results.

In Table 9, we provide results from extendeding our covariate set by including interest rates and (returns to) oil prices. We control for oil prices following Keller (2010) and Griffin et al. (2015) in order to take into account specificities of energy stocks. We use the crude oil spot price of Brent, FOB. To control for the opportunity costs of investment on a given date, we include the risk-free rate of return, namely, the German three-month government bond benchmark rate. The results in Table 9 are similar to our baseline results. The reson is that these additional covariates do not add much to the predictive power of the market model in our application. In the Appendix for further tables and

Table 9: ACARs by the Stages of the Proposal: Extended Covariate Set

Companies	Stages of the proposal		
	Climate levy proposal	Security reserve proposal	State aid assessment
RWE	0.009	-0.008	-0.102***
	(0.020)	(0.016)	(0.019)
E.ON	0.011	-0.019	-0.073***
	(0.017)	(0.014)	(0.013)

Notes: This table presents the average cumulative abnormal returns of E.ON and RWE from the announcements of each stage of the policy proposal. The event window is the five days centered around an announcement. The event window observations are excluded in the estimation of normal market performance. Normal market performance is predicted by a constant, returns to DAX30 index, returns to oil prices, and a risk free rate of return. The estimation window is the 90 days just prior to the event window. Standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$, **, *** $p < 0.01$.

figures (Appendix I), we present the corresponding results from announcement specific estimations in Table 17.

F Robustness Checks on the Baseline Distributional Assumption

In this section, we provide specification tests and robustness checks on the assumption of NID disturbances. The first panel of Table 10 presents the results from the estimation of normal market performance. For brevity, we focus on the announcements in stage 3. The second panel presents the p-values from various specification tests on the residuals. The Durbin test is for serial correlation where the null hypothesis is there is no serial correlation up to fifth order. The null is rejected if any lags of the residuals is significant in an auxiliary regression of the residuals on its lags. The null for the LM (Engle's Lagnrange multiplier) tests is that there is no p^{th} order autoregressive conditional heteroscedasticity (ARCH(p)) in the residuals. The third panel presents the alternative estimates for the standard errors: (i) robust standard errors for arbitrary forms of heteroscedasticity, (ii) standard errors based on pair-bootstraping, and (iii) Newey-West standard errors taking into account up to fifth order autocorrelations.

According to the results from the Durbin tests and the LM tests for ARCH(p) effects, there is no sign for serial correlation or heteroscedaticity. This result is further confirmed by the results in the third panel. The alternative estimates of standard errors are very close to our baseline estimates. There is only one exception to this general result, where the Durbin test rejects the null in the fifth column. However, the baseline and the Newey-West standard errors are still very close to each other, suggesting that the influence of significant lag order is minor.

Figure 21 illustrates the prediction intervals based on bootstrapping. Here, the contribution of sampling uncertainty is calculated based on pair-bootstrapped standard errors. As mentioned in the main text, this type of uncertainty is typically small which is the case in our application too. Therefore, the estimation method for sampling uncertainty have almost no influence on the width of the prediction intervals. In Figure 21, we assume IID errors in estimating the error uncertainty by resampling OLS-residuals with replacement (1000 repetitions) which is robust to departures from normality assumption. The width of these confidence intervals are close to their baseline counterparts. Table 11 presents the bootstrapped standard errors calculated from the empirical distribution of resampled OLS residuals. Again, the results are very close to their baseline counterparts.

G Confounding Events Investigation

This section presents details on the search for potential confounding events around announcements (3b) and (3c). We conducted a search for English- and German-language news in LexisNexis for the five-day window (working days) around each of these announcements, filtering by company name (RWE or E.ON, respectively). We restricted the search to business news in newswires and press releases to avoid a large number of news items appearing multiple times. Still, we were faced with a large number of very diverse news items in the event window for each firm.

We therefore manually categorized the news items according to their content and counted the number of news items on a specific topic in the given event window. We then

Table 10: Specification Tests and Alternative Estimates of Standard Errors

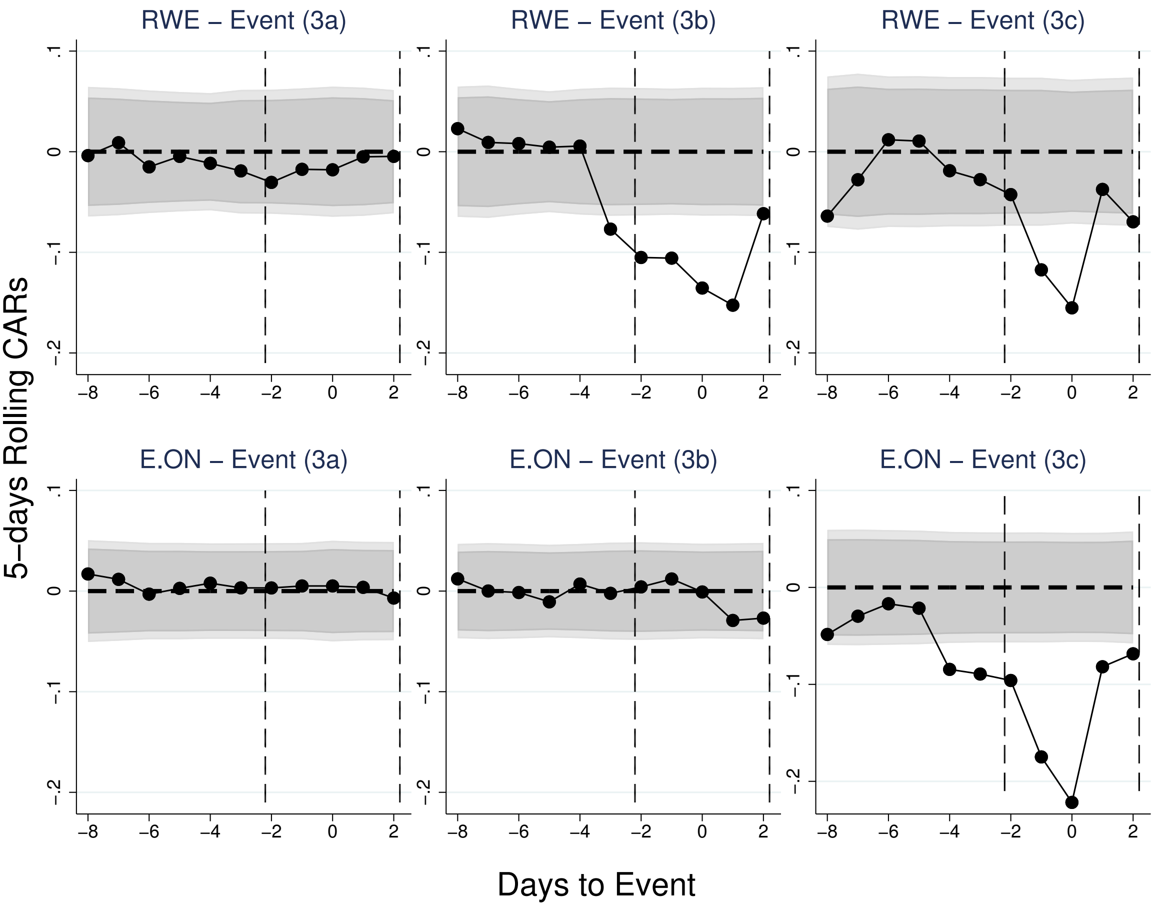
	RWE-(3a)	RWE-(3b)	RWE-(3c)	E.ON-(3a)	E.ON-(3b)	E.ON-(3c)
DAX30 Market Return	0.669	0.699	0.864	0.710	0.701	0.784
	(0.104)	(0.090)	(0.106)	(0.080)	(0.070)	(0.066)
Durbin test	0.683	0.255	0.521	0.506	0.063	0.355
LM test - order 1	0.997	0.626	0.716	0.391	0.717	0.421
LM test - order 3	0.875	0.824	0.908	0.484	0.796	0.797
LM test - order 5	0.929	0.911	0.976	0.320	0.797	0.903
Robust s.e.	0.087	0.076	0.106	0.075	0.065	0.090
Bootstrap s.e.	0.090	0.080	0.108	0.078	0.067	0.090
Newey-West s.e.	0.091	0.083	0.099	0.075	0.064	0.074

Notes: The first panel presents the results from the OLS estimation of normal market performance. The second panel presents the p-values from various specification tests on the residuals. The Durbin test is for serial correlation where the null hypothesis is there is no serial correlation up to p^{th} order. The null for the LM (Engle's Lagnrange multiplier) tests is there is no p^{th} order autoregressive conditional heteroscedasticity (ARCH(p)) in the residuals. The third panel presents the alternative estimates for the standard errors. Bootstrap standard errors are based on 1000 replications. The estimation of Newey-West standard errors include all the lags of the residuals up to fifth order.

assessed, based on content and press coverage, whether the news topics could be relevant drivers for the stock performance we observe in our event window. When we identified a potential company-specific confounding event for announcement (2b), we performed robustness analyses (see Section 7.2 for robustness checks on earnings announcements). For announcement (3c), we are more concerned with news that affects both RWE and E.ON, and thus performed robustness analyses for the case of a potential industry confounding event. Here we identified the nuclear provisioning issue as outlined in Section 7.2. LexisNexis provides a good overview of important issues around the event dates, but it was essential to complement this with own research on the events identified as potentially confounding. For instance, we found that the German business newspaper *Handelsblatt* was the first to report on the nuclear provisioning report on September 11; however, the first news items in LexisNexis mentioning this in the context of RWE appear on September 15.

In the Appendix for further table and figures (Appendix I), Tables 21, 22, 23, and 24 present the main news topics and numbers of news items on these topics for each

Figure 21: CARs and Bootstrap Prediction Intervals



Notes: This figure presents the CARs of RWE and E.ON from each announcement in the third stage of the policy proposal. The event window is the five days centered around an announcement (date 0) indicated with the dashed lines. In the figure, the days prior to the event window are the placebo announcement days. The event window and pseudo window observations are excluded in the estimation of normal market performance. The estimation window is the 90 days just prior to the pseudo window. The 90% and 95% bootstrap confidence intervals are indicated by shaded areas.

company and each event window.

H Estimation of Earnings Surprise

Effects of Earnings Announcements. We start by investigating the information content of quarterly earnings announcements for the market valuation of RWE and E.ON. If there is any investor reaction to earnings announcements, it should be due to the departure of announced earnings from investors' prior expectations, namely, the surprise in the information release.

We proxy the expected earnings with the quarterly earnings forecasts reported by the

Table 11: CARs and Bootsrapped Standard Errors

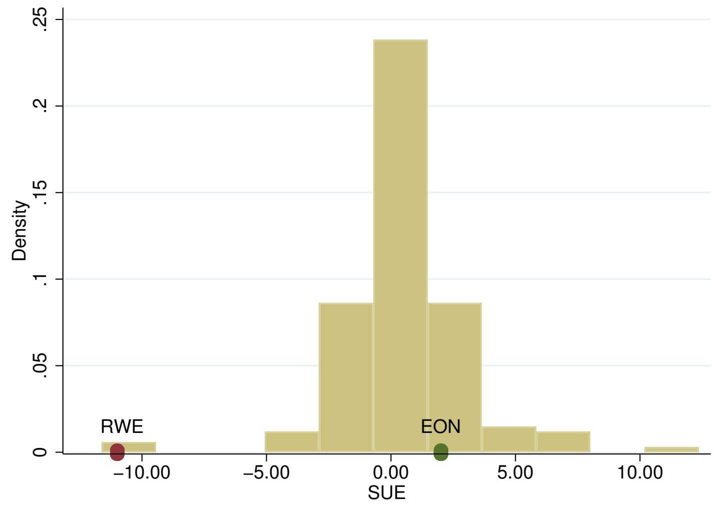
Companies	Announcements		
	(3a)	(3b)	(3c)
RWE	-0.020	-0.135***	-0.150***
	(0.033)	(0.032)	(0.036)
E.ON	0.004	-0.000	-0.220***
	(0.025)	(0.024)	(0.028)

Notes: This table presents the cumulative abnormal returns of RWE and E.ON from each announcement in the third stage of the policy proposal. The event window is the five days centered around an announcement. The estimation window is the 90 days just prior to the event window. Hence, the event window observations are excluded in the estimation of normal market performance. Bootstrapped standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Institutional Brokers Estimate System (I/B/E/S). It is the average of earnings forecasts by many analysts for a large number of firms. Our measure of surprise is the difference between announced earnings (AE) and mean forecasted earnings (MFE) normalized by the standard deviation of the forecasts. This measure is called the standardized unexpected earnings (SUE), which is provided by the Thomson Reuters Database. We employ the dataset on quarterly earnings announcements of DAX30 companies in 2015 and 2016. Figure 22 illustrates the distribution of SUEs in our sample. The SUEs for RWE and E.ON within the event (3b) window are indicated by dots. While the SUE is small and positive for E.ON, it is negative and large for RWE. This pattern has the potential to explain our findings for event (3b).

The technical details of estimating the marginal effect of SUE are provided in Appendix D.3. In words, we start by estimating the five-day CARs for all the earnings announcements in our sample by excluding the two earnings announcements by E.ON and RWE just before event (3b). Next, we estimate the marginal effect of SUE on the predicted CARs. The results are presented in the first column of Table 12. In the first regression, the effect of SUE on the five-day CARs are insignificant. However, this does not mean that the earnings announcement has no effect. In the following columns, we estimate the marginal effect of SUE on the individual ARs in the event window. Evidently, the only significant impact occurs on the event day. The size of the estimated effects on

Figure 22: Distribution of SUE



Notes: This figure illustrates the distribution of SUEs in our sample.

Table 12: Marginal Effect of Earnings Surprise

	5-Days CAR	ARs				
Relative distance		(-2)	(-1)	(0)	(1)	(2)
SUE	0.003	0.000	0.000	0.003***	-0.000	0.000
	(0.002)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)
Observations	120	120	120	120	120	120

Notes: This table presents the estimated marginal effect of SUE on the predicted CARs. Standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

the days before and after announcement dates is very small. Therefore, the size of the estimated effects on the five-day CARs and the estimated effect on the ARs on the event date are virtually the same.

In the next step, we employ these results to predict the CARs and ARs due to the earnings announcements of E.ON and RWE just before event (3b). The results are presented in Table 13. Panel A shows the CARs predicted by the SUEs, and Panel B shows the predicted ARs for each day of the event window. Reflecting the results in Table 12, the predicted CARs due to SUEs are positive and small for E.ON, while they are negative and large for RWE. Panel B shows that the impact of the earnings announcement occurs only on the event day, and the 95% confidence intervals support the estimated sign of the impacts. Other than on the event day, the size of the announcement

Table 13: Predicted CARs and ARs due to Earnings Surprise

Panel A: Predicted 5-day CARs due to earnings surprise					
Company	Date		Predicted CARs by SUE	95% Confidence Interval	
E.ON	8/12/2015		0.005	-0.000	0.011
RWE	8/13/2015		-0.032	-0.065	0.002

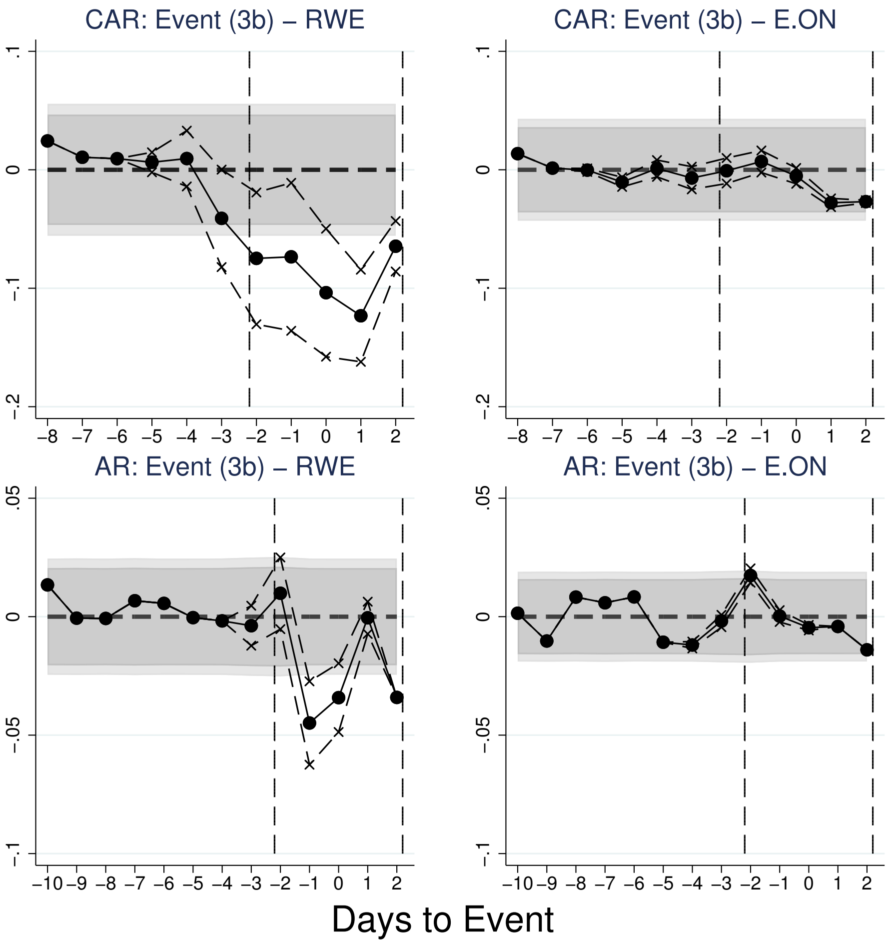
Panel B: Predicted ARs due to earnings surprise					
Company	Date	Relative Distance	Predicted AR by SUE	95% Confidence Interval	
E.ON	18/10/2015	-2	0.000	-0.001	0.002
	8/11/2015	-1	0.000	-0.002	0.003
	8/12/2015	0	0.006	0.002	0.009
	8/13/2015	1	-0.001	-0.003	0.002
	8/14/2015	2	0.000	-0.001	0.002
RWE	8/11/2015	-2	-0.001	-0.009	0.008
	8/12/2015	-1	-0.003	-0.018	0.013
	8/13/2015	0	-0.032	-0.050	-0.014
	8/14/2015	1	0.006	-0.009	0.020
	8/15/2015	2	-0.002	-0.009	0.005

Notes: This table presents the predicted CARs and ARs due to the earnings announcements of E.ON and RWE just before event (3b) .

effect is negligible and insignificant.

Correcting for the effect of earnings announcements. The rolling CARs and the ARs, corrected for the size of the predicted earnings announcement effect, are presented in Figure 23. This figure differs from the one presented in the main text in two ways. First, this figure illustrates the two sources of uncertainity, rather than the aggregated one presented in the main text. Second, the correction assumes a five-day event window for the earnings announcement. For example, the correction for RWE includes the dates between -3 and 1, as the earnings announcement of RWE is on date -1. This is also a conservative approach given that our results reveal that the effect of the earnings announcements is taking place on the announcement date only. The figure also illustrates the 90% confidence interval of the predicted earnings announcement effect constructed around the corrected CARs and ARs. The effect of the correction on CARs extends

Figure 23: Effect of Announcement (3b) Corrected for Earnings Surprise



Notes: This figure presents the ARs and CARs of E.ON and RWE from announcement (3b) corrected for the earnings announcements. The event window is the five days centered around an announcement (date 0) indicated with the dashed lines. The days prior to the event window are the placebo announcement days. The event window and pseudo window observations are excluded in the estimation of normal market performance. The estimation window is the 90 days just prior to the pseudo window. The 90% and 95% confidence intervals for the (uncorrected CARs) are presented as forecast intervals (shaded areas). The 90% confidence interval of predicted effect of earnings announcement is illustrated around the corrected CARs.

beyond the correction window due to the aggregation of ARs across days.

Figure 23 confirms the results presented in the main text and illustrates its details. An informal and conservative inference strategy is to compare the 90% confidence intervals. It is conservative, because a formal comparison requires calculating the standard error of the difference of these two random effects as in the main text. In our case, assuming that these two peredictions are uncorrelated is reasonable due to the way that these effects are predicted by using different samples. In this case, the standard error of the difference is equal to the square-root of the sum of variances. The standard error of the net effect is always smaller than the sum of the standard errors of the two predictions. Hence, the formal confidence interval, presented in the main text, is smaller than the sum of the confidence intervals of these two effects. However, Figure 23 is useful to illustrate the confidence intervals separately for expositional clarity. It is seen that the confidence intervals of the corrected CAR on the event day (day 0) and the predicted returns do not overlap. Figure 23 do not present the 95% confidence interval for the corrected CAR, which do overlap slightly. As a result, the corrected effect of event (3b) is still significant at reasonable levels, but much smaller than the baseline estimate.

I Appendix for Further Tables and Figures

Table 14: CARs by Announcement: Baseline Specification

Stages	Announcements	Companies		
		RWE	E.ON	EnBW
Climate levy proposal	1a	0.033	0.040	-0.004
		(0.034)	(0.029)	(0.039)
	1b	0.004	-0.011	-0.014
		(0.035)	(0.029)	(0.039)
	1c	-0.002	0.005	0.007
		(0.035)	(0.028)	(0.042)
Security reserve	2a	-0.004	-0.029	0.014
		(0.033)	(0.027)	(0.044)
	2b	-0.033	-0.028	0.017
		(0.032)	(0.027)	(0.043)
	2c	-0.002	-0.013	-0.007
		(0.030)	(0.028)	(0.048)
	2d	0.012	-0.007	0.011
		(0.030)	(0.027)	(0.049)
State aid assessment	3a	-0.020	0.004	-0.001
		(0.031)	(0.024)	(0.050)
	3b	-0.135***	0.000	-0.004
		(0.028)	(0.021)	(0.050)
	3c	-0.150***	-0.220***	-0.017
		(0.038)	(0.024)	(0.050)

Notes: This table presents the cumulative abnormal returns of all companies due to each announcement. The event window is the five days centered around an announcement. The estimation window is the 90 days just prior to the event window. Hence, the event window observations are excluded in the estimation of normal market performance. Standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 15: CARs by Announcement: Three-day Event Window

Stages	Announcements	Companies		
		RWE	E.ON	EnBW
Climate levy proposal	1a	0.000	0.012	0.020
		(0.027)	(0.023)	(0.031)
	1b	0.025	0.006	0.005
		(0.027)	(0.023)	(0.030)
	1c	-0.003	0.010	0.014
		(0.027)	(0.021)	(0.032)
Security reserve proposal	2a	-0.006	-0.026	0.024
		(0.026)	(0.021)	(0.033)
	2b	-0.013	0.003	-0.002
		(0.025)	(0.021)	(0.034)
	2c	0.003	-0.019	-0.026
		(0.023)	(0.021)	(0.037)
	2d	0.027	0.006	-0.002
		(0.022)	(0.020)	(0.038)
State aid assessment	3a	-0.004	0.000	0.015
		(0.024)	(0.018)	(0.039)
	3b	-0.108***	-0.010	-0.006
		(0.021)	(0.017)	(0.039)
	3c	-0.076***	-0.092***	-0.016
		(0.029)	(0.021)	(0.038)

Notes: This table presents the cumulative abnormal returns of all companies due to each announcement. The event window is the three days centered around an announcement. The event window observations are excluded in the estimation of normal market performance. The estimation window is the 90 days just prior to the event window. Standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 16: CARs by Announcement: Robustness to estimation window

Stages	Announcements	Companies		
		RWE	E.ON	EnBW
Climate levy proposal	1a	0.036	0.041	-0.002
		(0.035)	(0.028)	(0.040)
	1b	0.010	-0.008	-0.014
		(0.034)	(0.028)	(0.042)
	1c	0.000	0.009	0.005
		(0.038)	(0.029)	(0.034)
Security reserve proposal	2a	-0.009	-0.026	0.015
		(0.036)	(0.029)	(0.034)
	2b	-0.038	-0.025	0.018
		(0.034)	(0.030)	(0.040)
	2c	-0.003	-0.013	0.002
		(0.033)	(0.030)	(0.046)
	2d	0.009	-0.016	0.004
		(0.033)	(0.028)	(0.044)
State aid assessments	3a	-0.018	-0.002	-0.013
		(0.030)	(0.025)	(0.048)
	3b	-0.133***	0.001	-0.004
		(0.026)	(0.023)	(0.057)
	3c	-0.162***	-0.225***	-0.014
		(0.029)	(0.022)	(0.047)

Notes: This table presents the cumulative abnormal returns of all companies due to each announcement. The event window is the five days centered around an announcement. The event window observations are excluded in the estimation of normal market performance. The estimation window is the 60 days window ending at 30 days prior to the event window. Standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 17: CARs by Announcement: Extended Covariate Set

Stages	Announcements	Companies		
		RWE	E.ON	EnBW
Climate levy proposal	1a	0.032	0.046	0.010
		(0.035)	(0.029)	(0.040)
	1b	0.002	-0.013	-0.009
		(0.035)	(0.030)	(0.040)
	1c	-0.008	0.000	0.010
		(0.035)	(0.028)	(0.043)
Security reserve proposal	2a	-0.006	-0.029	0.015
		(0.033)	(0.027)	(0.044)
	2b	-0.035	-0.028	0.016
		(0.032)	(0.027)	(0.044)
	2c	-0.003	-0.013	-0.008
		(0.030)	(0.028)	(0.049)
	2d	0.012	-0.007	0.010
		(0.030)	(0.027)	(0.050)
State aid assessment	3a	-0.020	0.004	-0.005
		(0.031)	(0.024)	(0.051)
	3b	-0.135***	0.001	-0.006
		(0.028)	(0.021)	(0.051)
	3c	-0.152***	-0.222***	-0.016
		(0.038)	(0.024)	(0.051)

Notes: This table presents the cumulative abnormal returns of all companies due to each announcement. The event window is the five days centered around an announcement. Normal market performance is predicted by a constant, returns to DAX30 price index, returns to oil prices, and a risk-free rate of return. The estimation window is the 90 days just prior to the event window. Hence, the event window observations are excluded in the estimation of normal market performance. Standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 18: Synthetic Control: CARs and non-parametric p-values

Companies	Announcements		
	(3a)	(3b)	(3b)
RWE	-0.006	-0.130	-0.184
	(0.808)	(0.038)	(0.000)
E.ON	0.017	0.006	-0.243
	(0.885)	(0.231)	(0.000)

Notes: This table presents the synthetic-control estimates of the cumulative abnormal returns of RWE and E.ON from each announcement in the third stage of the policy proposal. The event window is the five days centered around an announcement. The estimation window is the 90 days just prior to the pseudo window. Hence, the event window observations are excluded in the estimation of normal market performance. Non-parametric p-values, following Abadie et al. (2015), are in parentheses. The p-values are the fraction of the units in the control group (donor pool) for which the estimated effects are at least as large as the estimated effect for the treated unit. If the pre-treatment match quality is distorted by some control units, the p-values can be conservative. In this case, one can normalize the estimated effects with pre-treatment RMSE reflecting the match quality. We do not apply this normalization. Pre-tretament RMSEs are illustrated in the main text.

Table 19: ACARs by the Stages of the Proposal: EnBW as the Control Unit

Companies	Stages of the proposal		
	Climate levy proposal	Security reserve proposal	State aid assessment
RWE	0.016	-0.016	-0.094***
	(0.031)	(0.027)	(0.033)
E.ON	0.015	-0.028	-0.065**
	(0.028)	(0.026)	(0.031)

Notes: This table presents the average cumulative abnormal returns of RWE and E.ON for each stage of the proposal by using EnBW as a control unit. The event window is the five days centered around an announcement. The estimation window is the 90 days just prior to the event window. Hence, the event window observations are excluded in the estimation of normal market performance. Standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 20: CARs by Announcement: EnBW as the Control Unit

Stages	Announcements	Companies	
		RWE	E.ON
Climate levy proposal	1a	0.037	0.044
		(0.053)	(0.049)
	1b	0.018	0.003
		(0.054)	(0.049)
	1c	-0.008	-0.002
		(0.055)	(0.049)
Security reserve proposal	2a	-0.018	-0.043
		(0.054)	(0.050)
	2b	-0.050	-0.046
		(0.053)	(0.050)
	2c	0.004	-0.006
		(0.056)	(0.055)
	2d	0.001	-0.019
		(0.054)	(0.054)
State aid assessment	3a	-0.019	0.005
		(0.055)	(0.054)
	3b	-0.131***	0.004
		(0.055)	(0.053)
	3c	-0.133**	-0.203***
		(0.061)	(0.055)

Notes: This table presents the cumulative abnormal returns of RWE and E.ON due to each announcement by using EnBW as a control unit. The event window is the five days centered around an announcement. The estimation window is the 90 days just prior to the event window. Hence, the event window observations are excluded in the estimation of normal market performance. Standard errors are in parentheses. Significance levels are indicated as * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 21: Type and Number of Company-related News around Event (3b), RWE

Topic	**Wed 12/08**	**Thu 13/08**	**Fri 14/08**	**Mon 17/08**	**Tue 18/08**
Earnings announcements (EA), financials	1	9		1	
Background on EA, company strategy	2	6			
Voting rights announcements		4			
Investments of company		2		5	3
Personnel appointments					2
Other					2

Source: Own summary based on LexisNexis, German- and English-language newswires and press releases, filtered by date and company name. "Other" includes local activities such as Czech gas management and local protests.

Table 22: Type and Number of Company-related News around Event (3b), E.ON

Topic	**Wed 12/08**	**Thu 13/08**	**Fri 14/08**	**Mon 17/08**	**Tue 18/08**
Earnings announcements (EA), financials	7				
EA and background, company strategy	16	6			
E.ON Russia financials	7	15		1	
E.ON UK financials	1	1	2	1	1
Voting rights announcements	5				
Investments of company	5		2		
Other	2			4	2

Source: Own summary based on LexisNexis, German- and English-language newswires and press releases, filtered by date and company name. "Other" includes local activities such as the opening of a plant, school visits, public relation activities related to a wind farm, etc., or the mentioning of E.ON in news about other firms. News items from Saturday and Sunday are assigned to the following Monday.

Table 23: Type and Number of Company-related News around Event (3c), RWE

Topic	**Thu 10/09**	**Fri 11/09**	**Mon 14/09**	**Tue 15/09**	**Wed 16/09**
Tendering and contracting	6		4		
Issues with power plant permissions	4	1	1	2	
Personnel issues	1	4			
Background on past stock performance		4	1		
Pending lawsuits		6	4		
Local operations & PR		6		1	
General industry news (gas supply)			**4**	**2**	
Nuclear provisioning Germany				**1**	**7**
Other		1	1	3	2

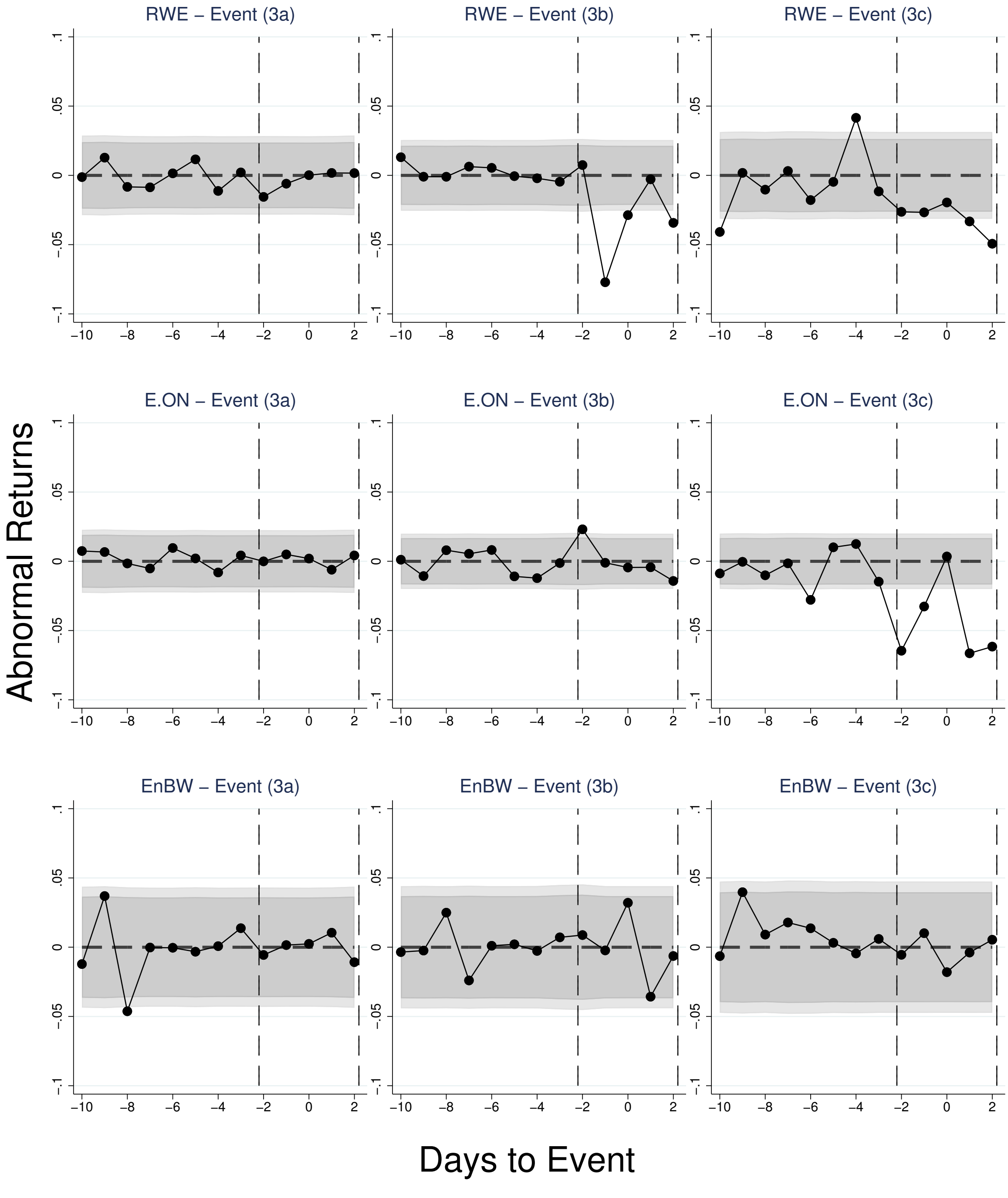
Notes: Industry-wide news in bold.
Source: Own summary based on LexisNexis, German- and English-language newswires and press releases, filtered by date and company name. News items from Saturday are assigned to the following Monday. "Pending lawsuits" relates to a gas procurement conflict where RWE may need to pay a penalty, for part of which the company already booked provisions. "Issues with power plant permissions" involve wind farm projects (new proposal after rejection) and a coal-fired power plant (court ruling that permit is upheld). "General industry news on gas supply" is a report on Iran as a potential new gas supplier for Europe. While this news is relevant industry-wide, we would expect it to have a positive impact on returns, if any.

Table 24: Type and Number of Company-related News around Event (3c), E.ON

Topic	**Thu 10/09**	**Fri 11/09**	**Mon 14/09**	**Tue 15/09**	**Wed 16/09**
Tendering and contracting		2			
Obligatory notifications on stocks and securities	3				
Nord-Stream pipeline	16	4	3		
E.ON's record low & background info on restructuring	10				
Stock market update mentioning E.ON	2	1	3		
Local customer relations and projects		2	6	3	2
General industry news (gas supply)			**1**	**3**	**1**
Nuclear provisioning Germany		**1**		**3**	
Other	1	1	2	1	

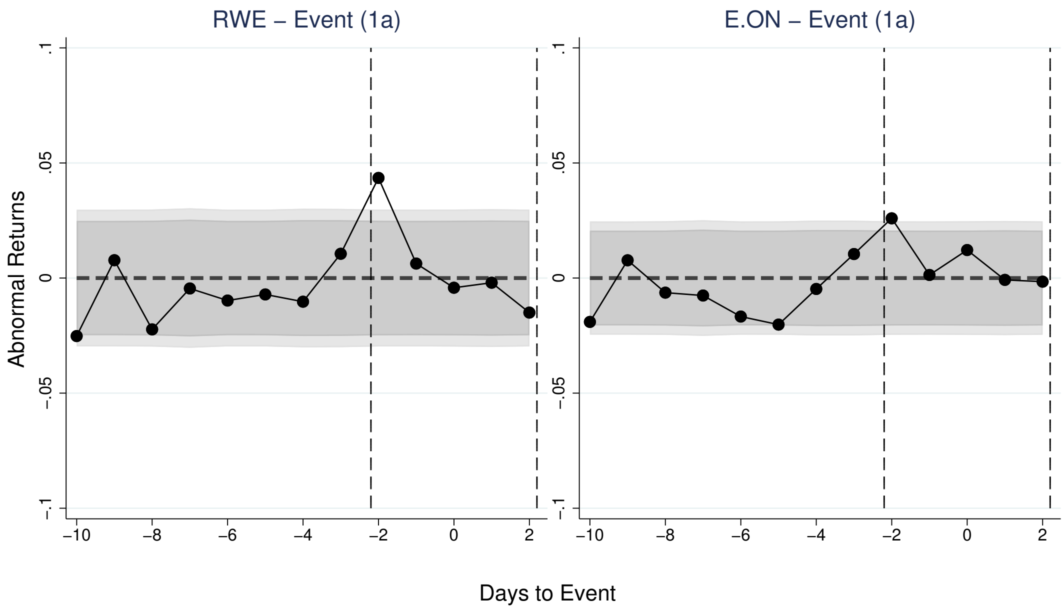
Notes: Industry-wide news in bold.
Source: Own summary based on LexisNexis, German- and English-language newswires and press releases, filtered by date and company name. News items from Saturday are assigned to the following Monday. "Nord-Stream pipeline" refers to business news over the shareholders' agreement on the pipeline, as well as political concerns voiced by Slovakia and Ukraine (calling the project "anti-European"). "E.ON's record low" on stock markets was recorded on September 10 and is why E.ON appeared in several general stock market updates. In background information, it was attributed to an unexpected announcement related to E.ON's company reorganization: In splitting the company into "clean" E.ON and "dirty" Uniper, E.ON would keep its nuclear business and the related liabilities. This decision is also relevant for the subsequent reaction of E.ON's shares to the nuclear provisioning assessment. "General industry news on gas supply" is a report on Iran as a potential new gas supplier for Europe. While this news is relevant industry wide, we would expect it to have a positive impact on returns, if any.

Figure 24: Abnormal Returns in the Placebo Tests



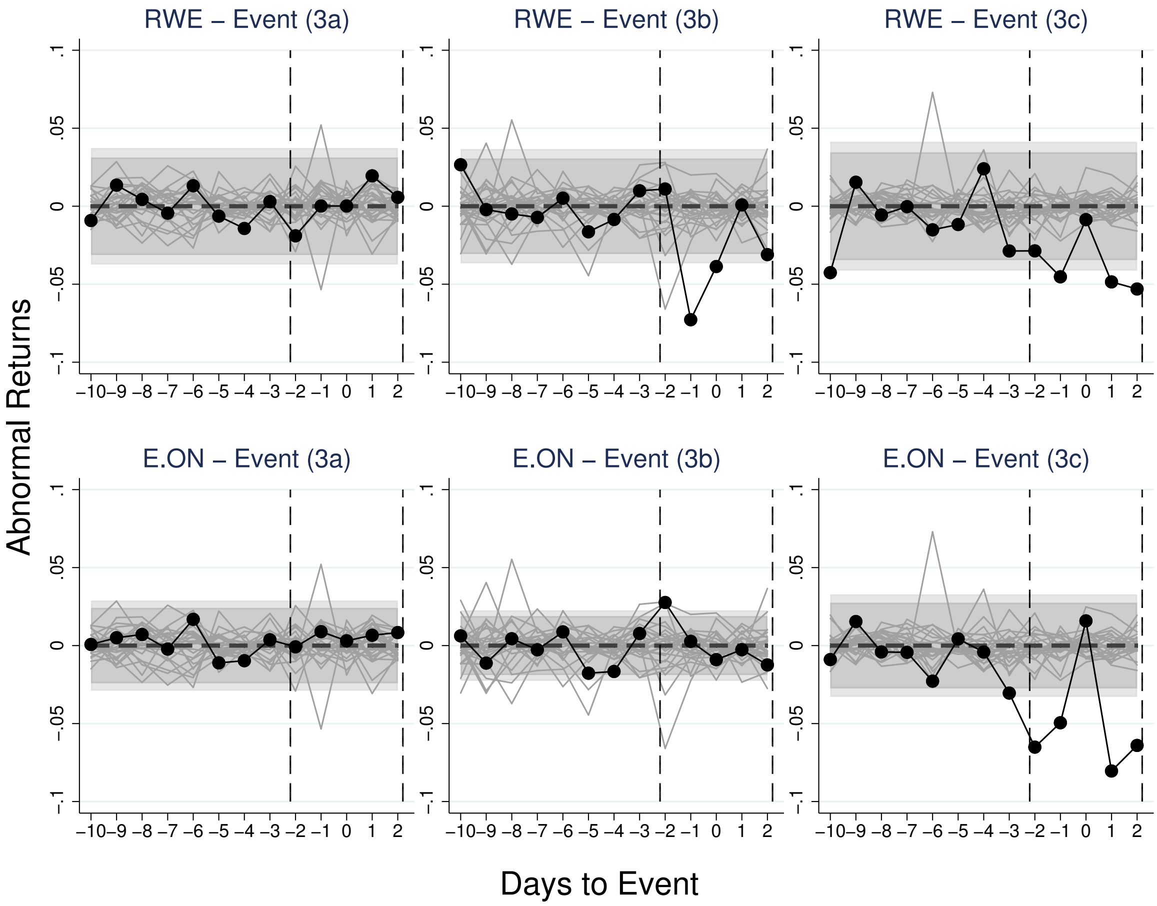
Notes: This figure presents the ARs of RWE, E.ON and EnBW from each announcement in the third stage of the policy proposal. The event window is the five days centered around an announcement (date 0) indicated with the dashed lines. In the figure, the days prior to the event window are the placebo announcement days. The event window and pseudo window observations are excluded in the estimation of normal market performance. The estimation window is the 90 days just prior to the pseudo window. The 90% and 95% confidence intervals are indicated by shaded areas.

Figure 25: Abnormal Returns around Event (1a)



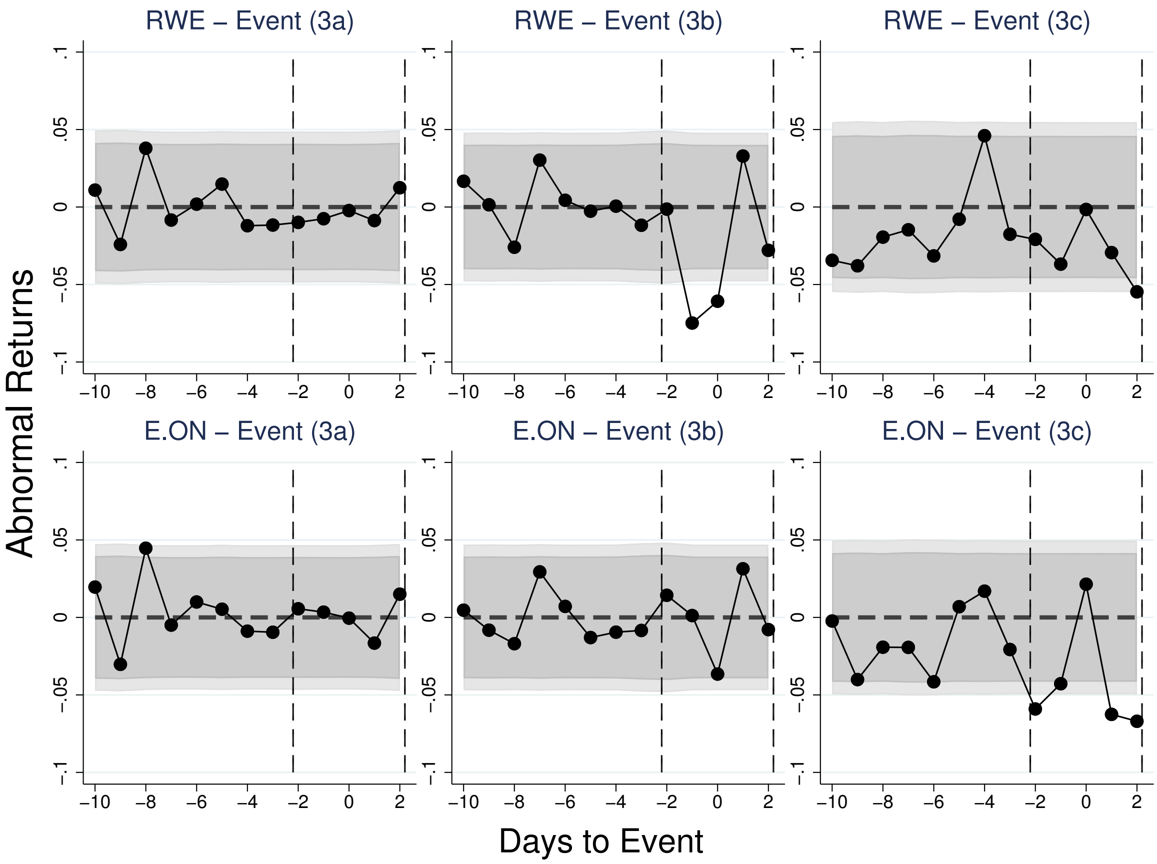
Notes: This figure presents the ARs of RWE and E.ON around Event (1a). The event window is the five days centered around an announcement (date 0) indicated with the dashed lines. In the figure, the days prior to the event window are the placebo announcement days. The event window and pseudo window observations are excluded in the estimation of normal market performance. The estimation window is the 90 days just prior to the pseudo window. The 90% and 95% confidence intervals are indicated by shaded areas.

Figure 26: Abnormal Returns from the Synthetic Control Estimations



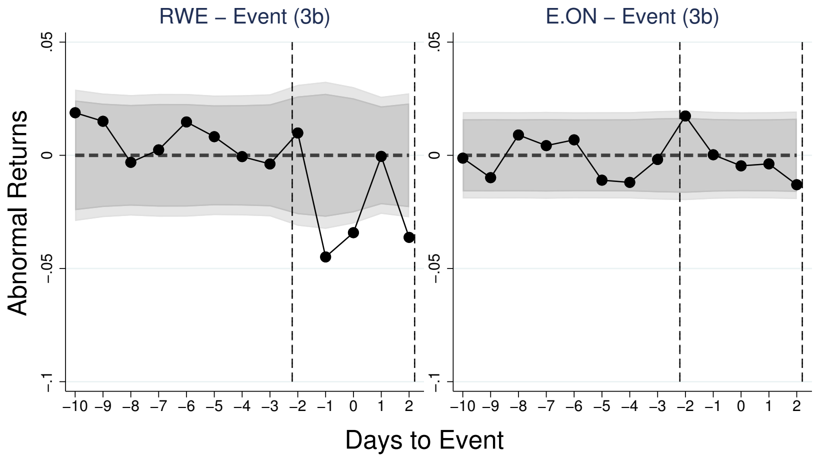
Notes: This figure presents the synthetic control estimates for ARs of E.ON and RWE from each announcement in the third stage of the policy proposal. The event window is the five days centered around an announcement (date 0) indicated with the dashed lines. In the figure, the days prior to the event window are the placebo announcement days. The event window and pseudo window observations are excluded in the estimation of normal market performance. The estimation window is the 90 days just prior to the pseudo window. The in-place placebo tests are illustrated with grey lines, and the grey areas are 90% and 95% confidence intervals constructed from the pre-treatment RMSE.

Figure 27: Abnormal Returns: EnBW as the Control Unit



Notes: This figure presents the estimates for ARs of E.ON and RWE from each announcement in the third stage of the policy proposal by using EnBW as the control unit. The event window is the five days centered around an announcement (date 0) indicated with the dashed lines. In the figure, the days prior to the event window are the placebo announcement days. The event window and pseudo window observations are excluded in the estimation of normal market performance. The estimation window is the 90 days just prior to the pseudo window. The 90% and 95% confidence intervals are indicated by shaded areas.

Figure 28: ARs for Announcement (3b) Corrected for Earnings Surprise



Notes: This figure presents the ARs of E.ON and RWE from announcement (3b) corrected for the effect of earnings announcements. The event window is the five days centered around an announcement (date 0) indicated with the dashed lines. The days prior to the event window are the placebo announcement days. The event window and pseudo window observations are excluded in the estimation of normal market performance. The estimation window is the 90 days just prior to the pseudo window. The 90% and 95% confidence intervals are indicated by shaded areas.