Electricity Prices during the Energy Crisis in Germany: The Role of Market Power

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Abstract

During the energy crisis in 2022, electricity prices in Germany soared to unprecedented levels, placing a significant burden on consumers. To explore the drivers of the high electricity prices, we develop an electricity dispatch model that simulates hourly equilibrium prices under the assumption of perfect competition. We then extend this model to account for firms exercising market power. By comparing the outcomes of the perfect competition and Cournot competition models with actual market data, we demonstrate that market power likely contributed to higher prices during the crisis, elevating them beyond what rising input costs alone would justify.

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Abbreviations

RWE	Rheinisch-Westfälisches Elektrizitätswerk AG
EnBW	Energie Baden-Württemberg AG
LEAG	Lausitz Energie Verwaltungs GmbH
GW	Gigawatt
GWh	Gigawatt hour
MWh	Megawatt hour
CO2	Carbondioxide
p.c.	per capita
SMARD	"Strommarktdaten für Deutschland" from Bundesnetzagentur
OMC	Operation and Maintenance Costs
EEX	European Energy Exchange
bn	Billion
€	Euros

θ	Conjectural variation parameter
t	Day
h	Hour
f	Firm
Q	Quantity demanded
q	Quantity produced
a	Intercept of demand curve
b	Slope of demand curve
p	Price
η	Price elasticity of demand
m	Quantity of must-run plant
MC	Marginal Costs
c	Costs
$\tilde{c}$	Slope of costs
e	Emissions
K	Capacity
γ	Time-controls
X	Matrix of controls for must runs

1 Introduction

Europe experienced a period of exceptionally high gas prices in 2022. These were caused by rising demand after many economies recovered from the Covid-19 pandemic as well as supply disruptions that occurred through the political backlash following Russia's invasion of Ukraine in February 2022. At the same time, wholesale electricity prices in Germany rose to an all time high (see Figure 1) which placed a burden on consumers struggling to pay high electricity prices.

In context of these concerns we aim to answer the question, whether the high electricity prices in Germany during the energy crisis in 2022 can be justified through rising marginal costs, i.e. higher gas prices, or if large electricity generators exercised their market power to artificially raise prices above the levels justified by increased marginal costs.

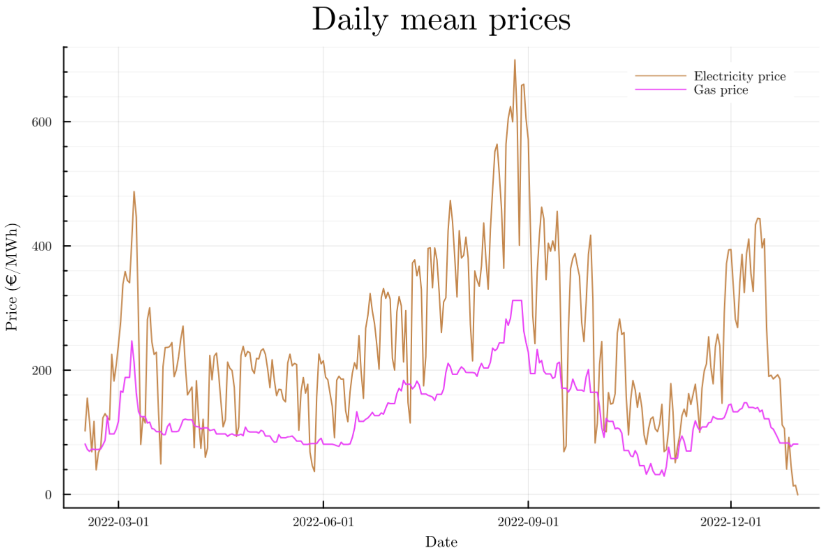


Figure 1: Daily mean electricity and gas prices from the 14.02.2022 to the 31.12.2022

In Figure 1 one can see the correlation between the rise in gas prices and high electricity prices, which is in line with Fabra and Reguant (2014), who find that electricity generators pass on higher production costs to consumers. However, in their latest market report, the German competition authority raised concerns about the abuse of market power in the electricity market during the year 2022 (Bundeskartellamt, 2023).

The liberalization of the German electricity market started in 1996. In the period after liberalization the market went from a competitive market with 30 smaller firms to a concentrated market with five big players (RWE, EnBW, LEAG, Vattenfall and Uniper) accounting for around 56 % of the installed capacities in Germany (see Figure 2) with the remaining 44 %

being shared among numerous smaller actors.

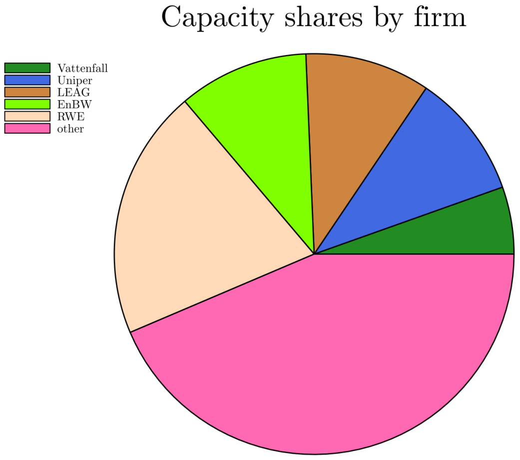


Figure 2: Shares of total capacity owned by five largest firms and fringe firms

The market shares of large electricity companies tend to decrease due to the expanding small-scale implementation of renewable capacity (Brunekreeft et al., 2016). Despite this trend the German competition authority notices a concerning trend of market concentration in the thermal power plant sector (Bundeskartellamt, 2023). The thermal power plant sector in Germany is dominated by the five big players (RWE, EnBW, LEAG, Vattenfall and Uniper) in Germany, even leading to RWE, EnBW and LEAG being indispensable for many hours during the year 2022, providing them with a favourable environment for strategic interaction and the exercise of market power (Bundeskartellamt, 2023).

Previous studies stated prices above competitive levels in Germany during different observational periods using a competitive benchmark approach (Weigt and Von Hirschhausen (2008), Müsgens (2006), Pham (2016)). In line with this literature, we develop a stylized electricity dispatch model of the German electricity market, providing estimates of electricity prices under the assumption of perfect competition. Comparing model predictions with actual market outcomes, we find that the competitive benchmark prices follow the same trends as actual market outcomes, i.e. increase with the gas price, but are unable to explain the exceptional price spikes observed in 2022.

Supporting the hypothesis that price differences between competitive benchmark prices and actual price outcomes can be attributed to the exercise of market power, we implement the first model in the context of the German electricity market that follows the approach of Bushnell et al. (2008). Therefore we expand our model to allow for markups consistent with strategic interaction resembling Cournot competition for the five largest players. In line with our hypothesis, this model provides a better fit of predicted market outcomes on observed prices.

We implement robustness checks on the benchmark model following Weigt and Von Hirschhausen (2008). These robustness checks do not change the conclusion that the Cournot competition model performs better at explaining prices during periods of high demand and leads us to support the concerns of the Bundeskartellamt (2023) regarding non-competitive market behavior. We find an average price-cost margin of 11 % leading to extra burden for consumers during times of high electricity prices. This corresponds to unjustified extra profits for electricity generating companies of 7.45 bn € during the year 2022.

The remainder of the paper is organized as followed. In Section 2 we give a brief overview of the relevant literature on market power in electricity markets. Section 3 introduces the theoretical framework of our two models under the assumptions of perfect and Cournot competition. Section 4 explains the input data and model calibration to the German market. The results are presented in Section 5, followed by a discussion of our findings and resulting policy implications in Section 6. The final conclusions are summarized in Section 7.

2 Literature review

The goal of our research is to address the concern of the German competition authority Bundeskartellamt (2023) by analyzing whether electricity generating firms in Germany exercised market power during the energy crisis in 2022. To do so, we look at the effect of non-competitive market conduct on electricity wholesale prices compared to competitive outcomes during that period. The microeconomic framework indicates that the exercise of market power raises prices within the market (Mas-Colell et al., 1995), since under perfect competition prices will be pushed down to the level of marginal costs.

The exercise of market power has been a steady concern in the context of electricity wholesale markets, since they exhibit several characteristics that favour the exercise of collusion and market power. Those characteristics include concentrated production, frequent interaction, multi-market contact, and a high degree of information transparency (Brown et al., 2023, Von Hirschhausen et al., 2007).

However, it is difficult to prove that firms exercise market power since marginal costs, corresponding to prices under perfect competition, are unobserved. The first influential study was published by Wolfram (1999) who implemented a competitive benchmark model to observe market power in the British electricity industry. This approach was followed by Borenstein

et al. (2002) who studied the Californian electricity market from 1998 to 2000. Through creating a competitive benchmark they decompose cost increases into production costs, inframarginal competitive rents, and costs resulting from the exercise of market power.
Both studies claim that large parts of high electricity prices, especially during high demand hours, cannot be explained by the competitive benchmark and are therefore due to the exercise of market power (Wolfram, 1999, Borenstein et al., 2002).

Looking at the impact of vertical arrangements in US-wholesale electricity markets, Bushnell et al. (2008) further developed this method by not only simulating a competitive market equilibrium but also providing a model of Cournot competition. By simulating a model specification where firms act as strategic market participants in an oligopoly and withhold capacities to artificially raise prices, they create a second counterfactual to bound the space of possible static, non-cooperative outcomes. They claim that the estimate for high demand hours, where firms can exercise market power, depend more on the residual demand than on the marginal costs using the Cournot model. Through this, potential biases in the estimation of costs, which are a concern for credibility of the competitive benchmark model, will have a smaller effect. In the following paper we will apply the methodology proposed by Bushnell et al. (2008) to the German electricity market for the year 2022 during the energy crisis.

In the context of Germany, Von Hirschhausen et al. (2007) use various methods to assess market conduct in the German electricity market and conclusively find that prices seem to follow oligopoly characteristics rather than a competitive benchmark. This creates a loss in overall welfare on top of shifting surplus from consumers to producers (Von Hirschhausen et al., 2007). Further econometric literature points out mixed results regarding market conduct in Germany. Graf and Wozabal (2013) use a conjectural variations approach, allowing for flexible interaction in between competitive and monopoly price formation and can not reject the hypothesis that there was no market power at play determining prices on the European wholesale electricity market. On the other hand, from an empirical analysis of intraday electricity prices, Hagemann (2015) supports the hypothesis that price spikes can be caused by owners of flexible generation technologies exercising market power during hours of high demand.

Following the approach of Borenstein et al. (2002), several studies implemented a competitive benchmark model in order to quantify the extent of market power as the difference between simulated competitive and observed market outcomes (Weigt and Von Hirschhausen (2008), Müsgens (2006), Pham (2016)). All studies find a differences of 12 to 25 % between their competitive benchmark model and observed market prices. However, they do not run a model with Cournot competition as proposed by Bushnell et al. (2008) to give more credibility to their results. This is of special concern due to the potential bias in marginal cost estimates which is not controlled for.

As of our knowledge, the effect of market power during the energy crisis in 2022 has not been studied quantitatively to date, although Fabra (2023) points out the possibility of abuse of market power in Europe during the energy crisis in 2022. With our thesis we aim to address this research gap and provide the first study applying the Cournot competition approach proposed by Bushnell et al. (2008) to the German market. Doing so, allows us to give previous market power estimates in Germany more credibility and reducing the marginal cost bias.

3 The Model

To simulate market outcomes under different assumptions of market conduct, we construct an electricity dispatch model, which solves for the partial equilibrium of hourly prices and quantities in the day-ahead wholesale electricity market. The model is based on the one used by Reguant (2019). The competitive benchmark model sets prices equal to marginal costs, whereas the Cournot model allows large firms to withhold quantities and charge a markup over marginal costs, varying with the degree of competition in the market.

3.1 Demand

Since Germany was a net exporter of electricity in 2022, we model demand as the sum of domestic and foreign demand (net exports). Each demand type is defined as

$$Q_{o,t,h}(p_{t,h}) = a_{o,t,h} - b_{o,t,h} p_{t,h} \quad \forall\ o \in \{foreign, domestic\} \tag{1}$$

where t and h refer to day and hour, respectively. We calibrate the slope of the demand curve $b_{o,t,h}$ and the intercept $a_{o,t,h}$ to match the observed market price $p_{h,t}$ and total quantity $Q_{o,h,t}$ in each hour, assuming different elasticites η_o for domestic and foreign demand as described in section 4, such that

$$b_{o,t,h} = \eta_o \, \frac{Q_{o,t,h}}{p_{t,h}} \tag{2}$$

The resulting total demand is equated to supply in every hour.

3.2 Supply

We model electricity supply from generation sources with zero marginal costs as well as thermal power plants with costs depending on efficiency, input costs and the carbon price. Given the relatively short-term focus of our model, we do not model investment and abstract from operation and maintenance costs. We also do not model start up costs.

3.2.1 Must runs

Considering the focus of our model on market power dynamics, we do not explicitly model generation sources with low or zero marginal costs such as solar, wind, hydro, nuclear and biomass but take their observed or forecasted (in the case of solar and wind) generation as given:

$$m_{s,t,h} = m_{s,t,h}^{observed} \quad \forall\ s \in \{hydro,\ nuclear,\ biomass,\ solar,\ wind\} \tag{3}$$

$m_{s,t,h}$ directly enters as the quantity produced from these sources in each hour, as we assign all of the above technologies zero marginal costs and thus model them as must-runs. We abstract from potential curtailment in the case of renewables and other factors like start up costs in the case of nuclear power.

3.2.2 Thermal power plants

To account for the market structure and different cost structures among firms, we aggregate the power plants owned by each firm on the technology level so that firms have a portfolio of one representative plant for each technology they own.

Marginal costs of thermal power plants depend on their efficiency, input costs and the carbon price:

$$\begin{aligned} MC_{f,i,t,h}(q_{f,i,t,h}) &= (c_{f,i} + \tilde{c}_{f,i}\ q_{f,i,t,h})\ p_{i,t}^{input} + e_i\ p_t^{\mathrm{CO_2}} \\ &\qquad \forall\ i \in \{hardcoal,\ lignite,\ natural\ gas,\ oil,\ waste\} \end{aligned} \tag{4}$$

where f refers to firm and i to technology. c and $\tilde{c}$ refer to the amount of input needed to produce one unit of electricity. Marginal costs for representative plants increase with the generated quantity $q_{f,i,t,h}$, since less efficient plants will be called to produce with higher demand (see estimation of c and $\tilde{c}$ in section 4). $p_{i,t}^{input}$ refers to the daily price for the production input of the technology. e_i refers to the emissions generated per unit of electricity, for each of which the daily carbon price $p_t^{CO_2}$ has to be paid. Thus, marginal costs $MC_{f,i,t,h}$ are defined for each representative plant owned by each firm as firms own differently efficient plants, with marginal costs varying each day depending in the prices of inputs and CO_2 and varying hourly since marginal costs rise with the produced quantity $q_{f,i,t,h}$.

In the perfect competition version of the model, thermal power plants produce up to the point where the equilibrium wholesale price equals their marginal costs or they reach their capacity limit at $K_{f,i}$:

$$q_{f,i,t,h}(p_{t,h}) = \begin{cases} 0 & \text{if } p_{h,t} \leq MC_{f,i,t,h}(q_{f,i,t,h}) \\ [0, K_{f,i}] & \text{if } p_{t,h} = MC_{f,i,t,h}(q_{f,i,t,h}) \\ K_{f,i} & \text{if } p_{t,h} > MC_{f,i,t,h}(q_{f,i,t,h}) \end{cases} \tag{5}$$

The price equals marginal costs for the price setting plant, while plants with marginal costs below the price earn the difference as the shadow value.

3.2.3 Cournot competition

Extending the model to simulate market outcomes when firms can exercise market power, we incorporate a markup over marginal costs consistent with the Cournot framework. Instead of producing up to the point where the price equals marginal costs, firms now choose their quantities to maximize profits (see Cournot setup in the Appendix A.1). The markup applies to the total quantity of each firm as the sum of the quantities supplied by each of their representative plants. The Cournot profit maximization setup yields the following set of first order conditions, which are to be simultaneously satisfied in equilibrium:

$$p_{t,h} = MC_{f,i,t,h} + \frac{q_{f,t,h}}{\sum_o b_{o,t,h}} \tag{6}$$

We generalize the first order conditions to allow the markup to be more flexible depending on market conduct:

$$p_{t,h} = MC_{f,i,t,h} + \theta \frac{q_{f,t,h}}{\sum_o b_{o,t,h}} \tag{7}$$

where θ allows for flexibility in the degree of market power through the size of markups in the market. $\theta = 1$ yields the markup in the standard Cournot framework as in (6), while $\theta = 0$ characterizes the case of perfect competition (see structural interpretation of θ in the Appendix A.1).

Since many fringe suppliers do not own enough quantity to exercise market power, we let the markup be positive only for the five largest firms, while fringe suppliers keep producing competitively as in (5). Firms with market power in the Cournot framework produce up to the point where the price equals their marginal costs plus the markup we allow for through θ:

$$q_{f,i,t,h}(p_{t,h}) = \begin{cases} 0 & \text{if } p_{t,h} \leq MC_{f,i,t,h}(q_{f,i,t,h}) + \theta \frac{q_{f,t,h}}{\sum_o b_{o,t,h}} \\ [0, K_{f,i}] & \text{if } p_{t,h} = MC_{f,i,t,h}(q_{f,i,t,h}) + \theta \frac{q_{f,t,h}}{\sum_o b_{o,t,h}} \\ K_{f,i} & \text{if } p_{t,h} > MC_{f,i,t,h}(q_{f,i,t,h}) + \theta \frac{q_{f,t,h}}{\sum_o b_{o,t,h}} \end{cases} \tag{8}$$
$$\textit{with } \theta = 0 \textit{ for fringe suppliers}$$

In the estimation, we calibrate the value of θ to optimally fit the observed market outcomes, showing how close strategic interaction in the market is to Cournot competition (see 4). Allowing some firms to have positive markups leads to higher equilibrium prices and lower quantities in all hours where plants that are owned by the largest firms set the price.

3.3 Equilibrium

The model is solved by finding the combination of production inputs so that supply equals demand for each hour of the day, taking into account the different price bidding structures under the assumption of perfect competition or Cournot competition. The equilibrium price will be the price that satisfies:

$$\sum_o Q_{o,t,h}(p_{t,h}) = \sum_s m_{s,t,h} + \sum_f \sum_i q_{f,i,t,h}(p_{t,h}) \tag{9}$$

The solution of the model yields the equilibrium price and the equilibrium domestic and foreign quantities for each firm and technology.

4 Data and Model Calibration

4.1 Demand

To calibrate the model we rely mainly on publicly available data for the period of 14.02.2022 to 31.12.2022. Market data including quantities, prices and exports for the joint day-ahead wholesale electricity market of Germany and Luxembourg is available in hourly resolution at the SMARD Portal (Bundesnetzagentur (2024)). SMARD is provided by the German Federal Network Agency for electricity, gas, telecommunications, post and railway markets. For their electricity market data they cooperate with ENTSO-E to ensure highest data quality.

To calibrate the demand curve as explained in Section 3.1, we need estimates for the price elasticity of demand. For the elasticity of domestic demand we rely on an estimate provided by Hirth et al. (2023), who finds a price elasticity of demand of -0.05 in the German electricity market.

We calculated an estimate for the export elasticity in our sample following the approach of Reguant (2019) and Bushnell et al. (2008). We regress the logarithm of exports on the logarithm of prices, which is instrumented by the predicted demand and the price of gas to avoid the endogeneity issue, as the price of gas is seen as exogenous for the importing country. Although the price of gas is not fully exogenous, it can be argued that the high fluctuations have been mainly influenced by political decisions following the Russian attack on Ukraine and not the demand from electricity generators. We also include controls for different times of the day (γ) and generation from wind, solar and the sources which are treated as must runs in our model (X):

$$ln(exports_t) = \eta ln(price_t) + \beta\gamma + \beta_n X + \epsilon \tag{10}$$

This yields an estimate for the export elasticity of -0.55, which is by 0.2 higher than the estimate by Reguant (2019) for California. This might be due to the greater interconnection and flexibility of the European electricity market. With the elasticity and the market data we calibrate the demand functions as described in Section 3.1.

4.2 Supply

On the supply side we rely on data from the Open-Power-Sytems database (Open Power System Data (2020)) which provides a dataset with capacity, efficiency and operating company for each power plant in Germany. We assign firm ownership to each plant using publicly available data on company structures and subsidiaries of the five largest firms RWE, EnBW, LEAG, Uniper and Vattenfall and gather all remaining plants as a representative fringe firm "other". Within each firm, we aggregate data on the technology level to construct firm portfolios of one representative power plant of each technology that each firm owns.

To account for heterogeneity in efficiency of the plants that make up each representative plant, we accumulate the capacity of power plants of the same technology within each firm from the most efficient to least efficient plant and perform linear regressions of efficiency on accumulated capacity. The slope of the regression yields the estimate for marginal costs increasing with quantity as described in Section 3.2.2. The intercept, approximating the efficiency of the most efficient plant is taken as the starting value. This way, costs for the representative plants rise when they produce higher quantities, following the logic that the power plants making up the firm portfolios will be called into production in order of their efficiency.

As described in Section 3.2.2, the efficiency estimates are multiplied by the price of the resource to obtain the marginal costs for each hour of the day and depending on the quantity.

Resource prices for oil, lignite and hard coal are taken from a report of the German Federal Statistical Office (Destatis, 2023). Among input prices, the largest price fluctuations are observed for the price of gas. To model gas prices, we requested data of the daily spot market price of gas from the European Energy Exchange (EEX).

In reality, power plant operators may not need to pay the spot market price but rather rely on long-term contracts. However, these contracts are private information and therefore can not be modelled by researchers. Nevertheless, it is appropriate to model the marginal costs with the spot market prices, as they represent the opportunity costs of gas for the given day. This assumption seems to be supported by Figure 1 where gas prices are correlated with electricity prices without a lag.

Emissions are calculated based on the efficiency of the plant together with the emission factor estimate of the fossil fuel used for generation, corresponding to the amount of CO_2 emitted from producing one unit of electricity. The emission factor is extracted from a report of the German Environment Agency (Umweltbundesamt, 2016). Power plants have to pay the EU-ETS carbon price for each ton of carbon they emit. Data for daily average EU-ETS prices is extracted from Ember-EU.

Capacity data is also reported in the Open-Power-Sytems dataset (Open Power System Data (2020)). However, in July 2020 the German parliament passed the Act to Reduce and End Coal-Fired Power Generation (Press and Information Office of the Federal Government (2020)), requiring the total capacity of hard coal and lignite fired plants to be reduced to around 15 GW by 2022. Since the total capacity of hard coal and lignite plants in our data exceed these limits, we limit capacity of hard coal and lignite plants to 72 % and 83 %, respectively, in line with the 15 GW limit.

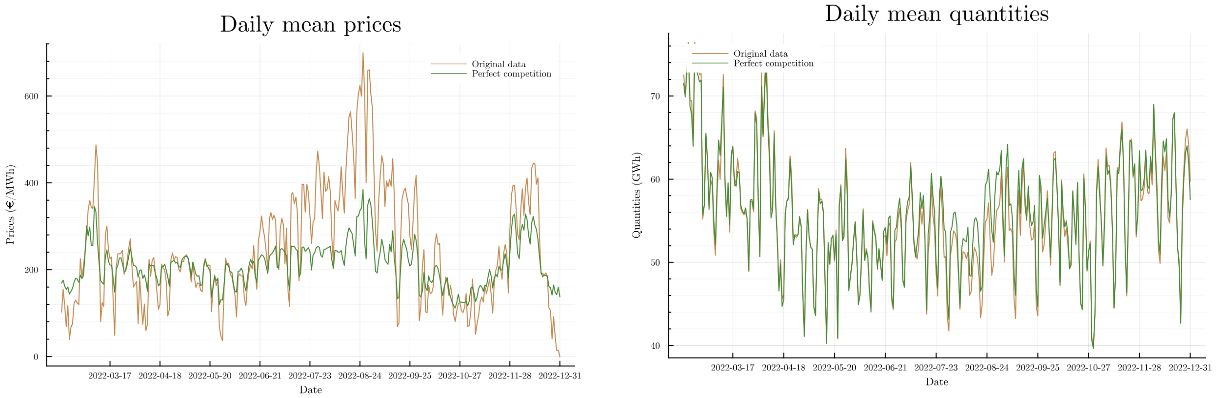
We do not explicitly model biomass, nuclear and hydro electricity generation but rather treat these inputs as must-run technologies which are used in the model at their observed generation at each hour. Data on generation of these technologies is taken from SMARD Portal (Bundesnetzagentur (2024)). Solar and wind are also treated as must-runs. We include the amount predicted to be generated one day in advance as the generated quantity in our model, since we model the day-ahead wholesale electricity market where the expectation of generation from renewables is crucial for bidding behavior. Data for the generation forecast is also taken from the SMARD Portal (Bundesnetzagentur (2024)).

An overview of calibrated supply side model inputs can be found in the Appendix (A.2). Codes for our model and datacleaning are linked in the Appendix section A.3.

5 Results

5.1 Competitive Benchmark Model

Figure 3 shows the daily means of hourly equilibrium prices and quantities from our calibrated competitive benchmark model of the German electricity market in 2022 as well as the observed market outcomes. As seen in Figure 3a, the modelled prices follow the same trend as the original prices. Periods with lower average prices and low variation, as in April and May, seem to be well approximated by the model with perfect competition. However, the rise in input prices is not able to explain the large price increases as observed e.g. during the summer months, where competitive prices remain far below observed prices. This leads us to conclude that the exceptionally high prices during the energy crisis can not be sufficiently explained by the change in resource prices, as accounted for in our model.



(a) Daily mean prices with original data and model with perfect competition

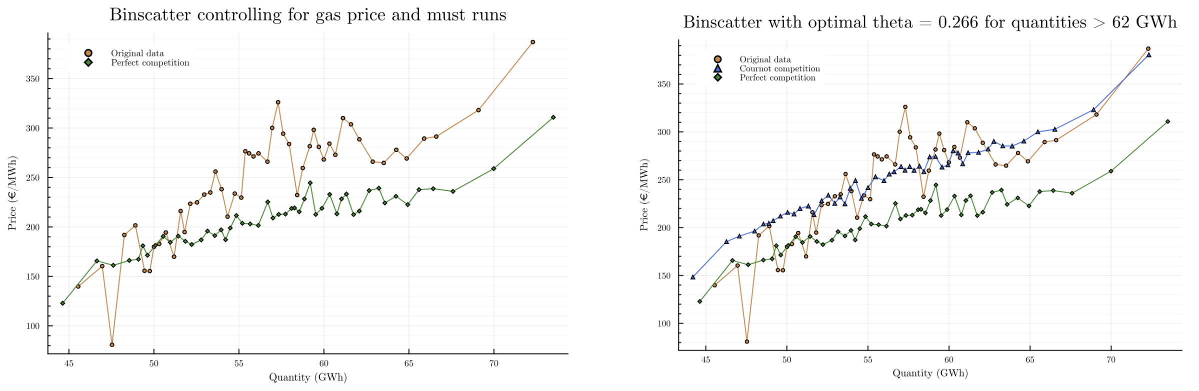
(b) Daily mean quantities with original data and model with perfect competition

Figure 3: Results of the competitive benchmark model

Figure 4a shows the residualised equilibria of prices and quantities in the model and the original data after controlling for variations in the quantity of must runs and gas prices through a binscatter regression. We apply the k-means method to cluster the dataset that is used for the binscatter regressions to 500 representative hours, to reduce dimensionality.

Consistent with the findings above, the competitive benchmark provides a reasonable prediction for the low-demand section of the data. With rising quantities, the observed equilibrium outcomes move farther away from the ones predicted by the model.
Reasons for divergence of the model from the original data could be unmodelled startup costs, transmission constraints, unobserved high fuel prices, but also the exercise of market power (Wolfram (1999), Borenstein et al. (2002), Weigt and Von Hirschhausen (2008),

Alpino et al. (2023), Reguant (2014)). The fact that the model diverges increasingly for high quantity hours supports the hypothesis of market power being a contributing factor to price differences, since the market gets less competitive at higher demand hours when most fringe suppliers have already maxed out their capacity. This gives room for owners of large capacities to raise prices above competitive levels (Von Hirschhausen et al., 2007). To support this hypothesis, we explicitly model market outcomes under the assumption of Cournot competition to assess whether the original data is more conclusively described by these outcomes.



(a) Model of perfect competition

(b) Adding model with market power and optimal theta

Figure 4: Binscatter of clustered data and the model of perfect competition controlling for the price of gas and the quantity of must runs. A model of Cournot competition is added to further investigate whether market power is determining price setting. The optimal theta parameter is calculated by minimizing the sum of squares between the model and the original data for quantities > 62 GWh.

5.2 Calibrating optimal θ

Previous studies on the German market took the model with perfect competition as a competitive benchmark model and calculated Price-Cost Margins as the difference to the original data (Weigt and Von Hirschhausen (2008), Müsgens (2006), Pape et al. (2016)). Competitive benchmark models are sensitive to errors in the estimation of costs, therefore we follow the approach by Bushnell et al. (2008) and simulate a model where equilibrium prices and quantities are formed under the assumption of strategic interaction of firms in Cournot competition. Potential biases in the estimation of costs, which are a concern for credibility of the competitive benchmark model, will have a smaller effect through introducing the Cournot competition model as a counterfactual (Bushnell et al., 2008).

We extend our competitive benchmark model by the markup term explained in equation (8) to obtain a model of Cournot competition, in the following also referred to as model with market power. The model allows for different forms of conduct by varying the parameter θ, resulting in markups closer to perfect competition (no markup) or Cournot competition. We calibrate θ to achieve the best fit of the model to observed market outcomes during high demand hours, as Bushnell et al. (2008) find that market power explains prices especially during peak demand hours. We iterate over values of θ until the sum of squared residuals between the original and simulated market outcomes during hours with demand $>$ 62 GWh is minimized. As seen in Figure 4b, the market power model follows observed outcomes quite closely during peak hours with an optimal θ of 0.266.

Since θ indicates the degree of deviation from perfect competition outcomes ($\theta = 0$) towards Cournot interactions where firms' decisions are determined by profit maximization through choice of quantities in strategic interaction ($\theta = 1$, see also Appendix A.1), $\theta = 0.266$ indicates that firms are not able to behave as in a pure oligopoly framework. This is consistent with the fact that they face the competition of not only other strategic firms, but also fringe suppliers, especially during low to medium demand hours. However, $\theta = 0.266$ clearly indicates a deviation of market conduct from perfect competition outcomes during these hours.

5.3 Model with Cournot Competition

Having calibrated the model with the θ that best fits the original data for peak demand hours, we run the competitive benchmark and the Cournot competition model for the unclustered dataset from 14.02.2022 until the 31.12.2022.

Figure 5 shows the market outcomes of the perfect competition model (green), the market power model (blue) and the original data (brown, individual data points in grey) after controlling for the gas price and quantity of must runs. Below quantities of 50 GWh, the original data is fairly well characterized by the competitive outcomes. However, for quantities above 55 GWh, the Cournot model best describes the price setting behavior. This is strongly aligned with the results of Bushnell et al. (2008).

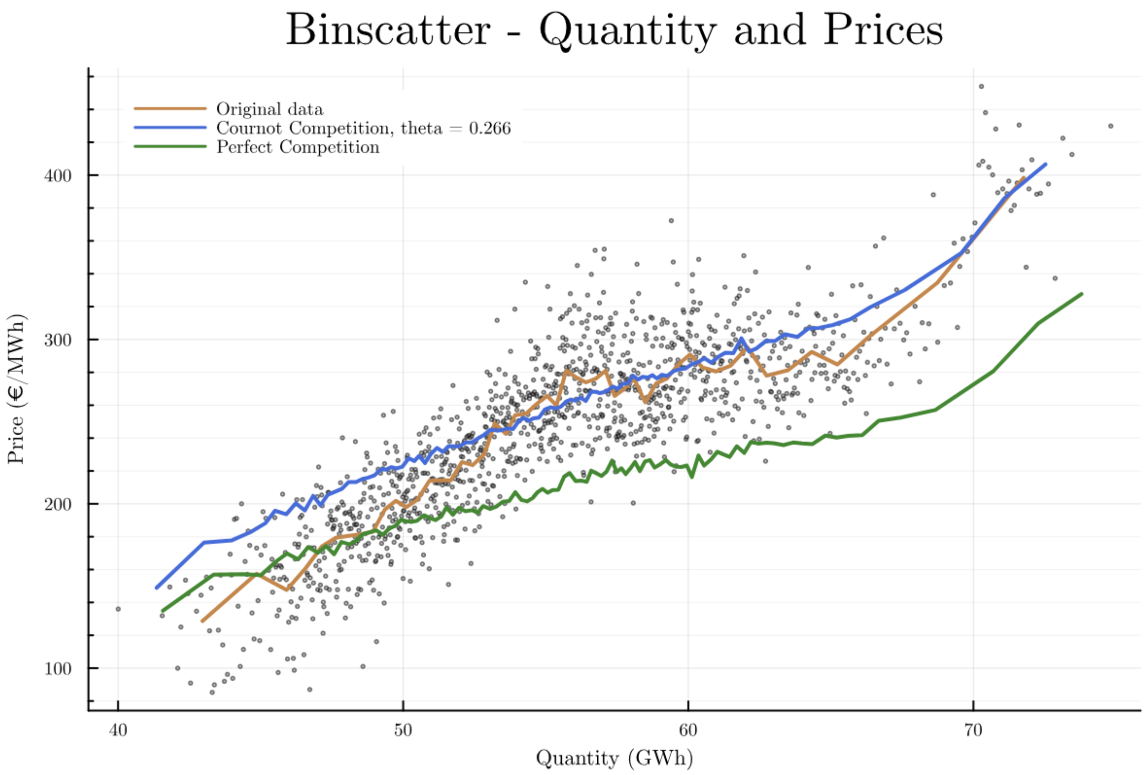


Figure 5: Binscatter of original data and the model of perfect competition controlling for the price of gas and the quantity of must runs. A model of Cournot competition is added to control for market power determining price setting. The grey dots represent the residualized values of the original market outcomes.

The good fit of the Cournot competition model with the original data after controlling for variations in the quantity of must runs and renewables supports the hypothesis that high prices during the energy crisis can be conclusively explained by the increase in resource prices and the exercise of market power through RWE, EnBW, LEAG, Vattenfall and Uniper. However, we are aware of limitations of our model, including startup costs, transmission constraints and an ideal simulation of marginal costs. As this could bias our results (Reguant (2014), Weigt and Von Hirschhausen (2008)) and shift the prices predicted by the competitive benchmark model upwards, absolute differences to the benchmark should be interpreted with caution.

5.4 Robustness checks

To control for some of the limitations and ensure the validity of our results we perform three robustness checks. The first two robustness checks are based on Weigt and Von Hirschhausen (2008). In their examination of market power in the German electricity market they check model performance after limiting the capacity of power plants. This accounts for the reasoning that plants may lose capacity over time, or some power plants in the dataset might not be operating anymore. As seen in Figure 6, limiting the capacity of all plants to 90 % (on top of the limit already imposed on coal plants) only marginally raises the competitive benchmark outcomes.

Weigt and Von Hirschhausen (2008) proceed by increasing fuel costs by 5 %. We go one step further and increase all marginal costs by 10 %. Doing this, we account for potential unobserved fuel price increases, but also for many more factors like startup costs, transmission constraints or overly optimistic efficiency estimates in our input data. This can be seen as a conservative estimate of the competitive benchmark model.
Figure 7 shows, that even after introducing this generous markup to the competitive benchmark model, the market power model still explains actual outcomes better than the adjusted benchmark model during peak demand times.

We extend the robustness checks performed by Weigt and Von Hirschhausen (2008) by including an approximation for operation and maintenance costs (OMC) in our model. We do not include them into our original model since they are (a) subject to private information of the generators (Alpino et al., 2023) and (b) almost impossible to map exactly as marginal costs for the corresponding unit. As a robustness check and approximation we added OMC's of 10 € per unit to the marginal costs of generation, overstating the published OMCs by the U.S. Energy Information Administration (2023). This exercise aims to show the reaction of our model to the inclusion of OMCs.

Including OMC´s raises the level of the competitive benchmark model (Figure 8), but as with the other robustness checks, our model with Cournot competition still best describes the original data, reinforcing the hypothesis that RWE, EnBW, LEAG, Vattenfall and Uniper used their market power to artificially raise prices during the 2022 energy crisis.

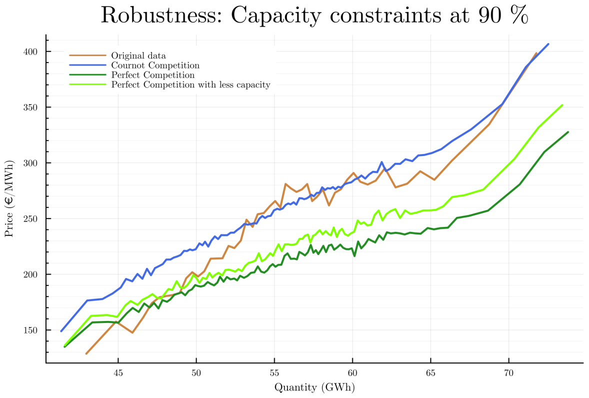


Figure 6: In this model capacities of thermal plants are limited to 90 % of their capacity in our dataset.

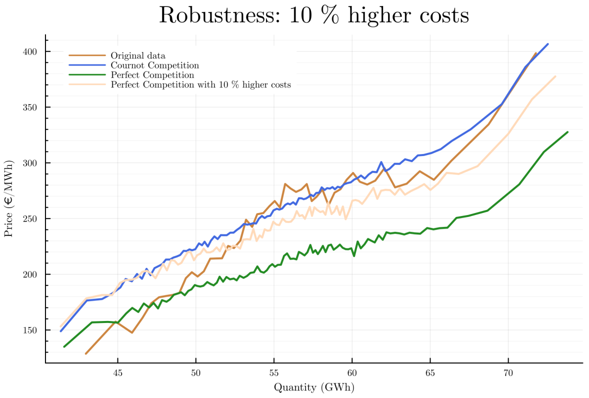


Figure 7: The percentage markup on costs is modelled as a 10 % markup on marginal costs for each power plant.

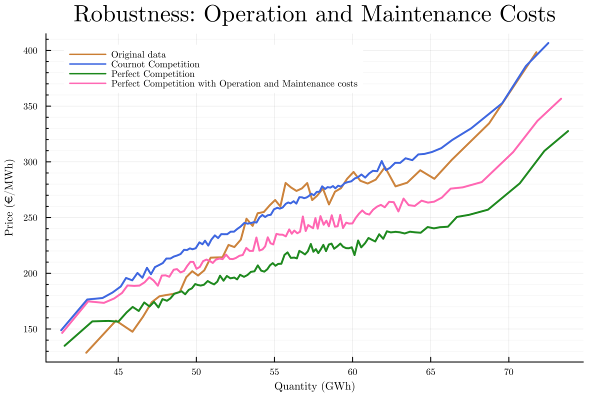


Figure 8: Operation and Maintenance costs are modelled as a 10 € markup on marginal costs for each power plant.

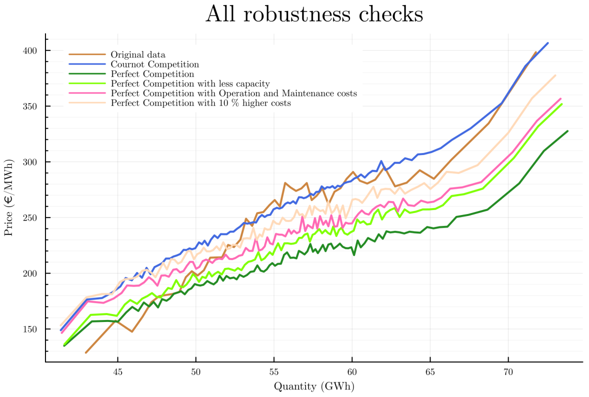


Figure 9: Comparison of all robustness checks, simulated outcomes of both models and original data.

5.5 IO-measures

Computing the Herfindahl Hirschmann Index over available capacities yields an index of 741, generally indicating a market that is not overly concentrated (Calkins, 1983). However, our simulations and robustness checks have shown that market power has likely played an important role for the price setting behavior during the energy crisis.

This contradiction can be explained by the characteristics of the electricity market. One explanation for this could be that RWE, EnBW and LEAG are seen as indispensable for many hours, as pointed out by Bundeskartellamt, 2023. Additionally, Borenstein et al. (1999) emphasize the fact that traditional concentration measures like the HHI are not overly conclusive about the possibilities to exercise market power in electricity markets due to its unique characteristics like non-storability of the product, relatively inelastic demand and transmission constraints.

To compute the effects of market power on prices, consumers and firms' profits we deviate from previous studies in Germany which have calculated the difference between the competitive benchmark model and the observed prices (Müsgens (2006), Weigt and Von Hirschhausen (2008), Pham (2016)). We follow the approach by Bushnell et al. (2008) comparing the competitive benchmark model with the Cournot competition model to remove fluctuations in the original data due to other factors which we would wrongly assume as market power. We calculate the impacts only for outcomes after the threshold of 55 GWh, where the Cournot competition model represents the original data better than all other simulations, which is in line with the finding of Bushnell et al. (2008) that market power can mainly be exercised in high demand hours.

All measures are calculated for an upper bound, comparing original prices to the competitive benchmark model without additional costs, and a lower bound comparing them to the most conservative benchmark model with 10 % higher marginal costs. The average measure refers to the mean of results across all four model simulations of the benchmark model (Table 1).

	Lower bound	**Upper bound**	**Average**
Mean Price-Cost Margin	5.08 %	17.45 %	11.28 %
Extra profits of firms	3.3 bn €	11.5 bn €	7.45 bn €
Costs per Capita	40.52 €	140.5 €	90.92 €
Napolitanas de Chocolate (per capita)	42 NAP	147.8 NAP	99 NAP

Table 1: Lower bound refers to the difference to the robustness check with 10 % cost increase, the upper bound refers to the difference to the competitive benchmark model and average is the mean over all calculated scenarios

The difference between prices and marginal costs can be seen as a measure of market power as price derivations from marginal costs indicate a market structure that deviates from perfect competition (Cowling and Waterson, 1976). Compared to our competitive benchmark model, firms increased prices by 17.45 % during high demand hours above the prices that are justified by the increasing prices of gas and other inputs during the energy crisis. The lower bound of this estimate is 5.08 % with an average of 11.28 % across all of our simulations.

This increase in prices resulted in an extra profit for the electricity generating firms in Germany between 11.5 bn € and 3.3 bn €, averaging at 7.45 bn €.

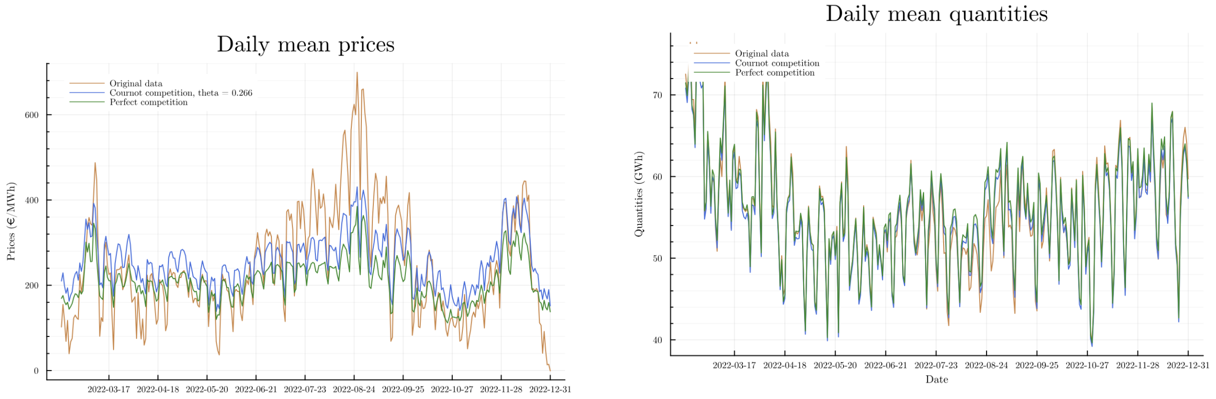
These extra profits of firms can be seen as costs for consumers since surplus is transferred from consumers to producers when prices are raised through market power. Those costs average at 90.9 € per capita with a lower bound of 40.52 € and an upper bound of 140 € per capita. Translated into a consumer good, the exercise of market power through RWE, EnBW, LEAG, Vattenfall and Uniper is estimated to create additional costs to each German citizen that are the equivalent of 99 Napolitanas de chocolate for the observed time period between the 14.02.2022 until the 31.12.2022. These results do not account for the dead weight losses resulting from deviations from the perfect competition equilibrium which could raise the costs per capita even further (Von Hirschhausen et al., 2007). Therefore our estimates can be seen as conservative.

Recapping, our results substantiate the concern of the Bundeskartellamt (2023) that electricity generating firms exercised market power during the energy crisis in the year 2022, placing a burden on consumers. Although we can not fully prove the extent of market power, we show that price setting behavior of electricity generators can be conclusively explained by our model with market power. This price setting behavior leads to additional costs for consumers in the time of crisis.

5.6 Market behavior over time

The results presented above build on the outcomes from the Cournot model where θ is fit to optimally match the prices during the highest demand hours of the whole year as described in Section 5.2.

Figure 10 shows the daily mean prices and quantities predicted by the perfect competition model and the Cournot model as well as the observed market outcomes. Quantities are described fairly well, with on average higher quantities predicted by the perfect competition model due to lower prices. As mentioned in Section 5.1, competitive prices as predicted by our model are lower than actual prices for most days of the year. The average price of the year in the perfect competition model is 210.88€, while the actual prices averaged at 246.05€. The Cournot model with $\theta = 0.266$ approximates the average price better with 255.99€. The higher average in the Cournot model is mainly due to the overstatement of prices for quantities less then 55 GWh. Figures 10a and 11 show that prices follow the Cournot prices well especially during high price periods in the first and last months of our sample.



(a) Daily mean prices with original data, model with perfect competition and model with Cournot competition ($\theta = 0.266$)

(b) Daily mean quantities with original data, model with perfect competition and model with Cournot competition ($\theta = 0.266$

Figure 10: Unclustered model outcomes over the year, $\theta = 0.266$

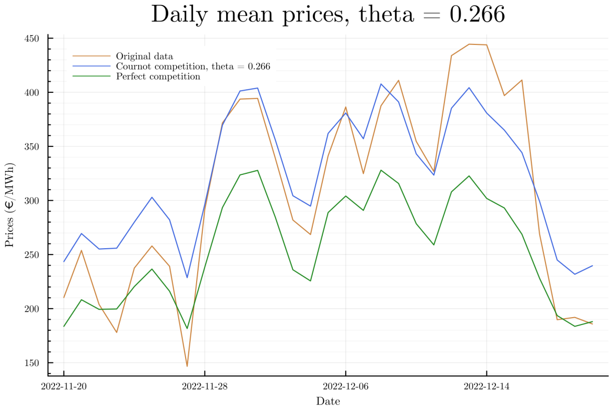


Figure 11: Daily mean prices (original, competitive and with Cournot competition) for November and December 2022 with $\theta = 0.266$

However, the summer months of 2022 exhibited exceptionally high prices, which go beyond the outcomes predicted by our model with θ fit to match the whole sample (see Figure 10a). In the public debate, the large price spikes were attributed to the increase of the gas price. Looking back at Figure 1, gas prices were merely above the level already observed during the first price spikes in March. However, Figure 10a shows that competitive prices, accounting for the increase of the gas price, remain far below the observed prices.

High electricity prices were also attributed to increasing electricity exports to e.g. France and Austria due to maintenance issues of nuclear plants in France and plunges in domestic generation in Austria due to weather conditions.
Looking at Figure 12 the observed price spikes can only partially be attributed to increased exports, as a period of higher exports started only at the end of the high electricity price period.

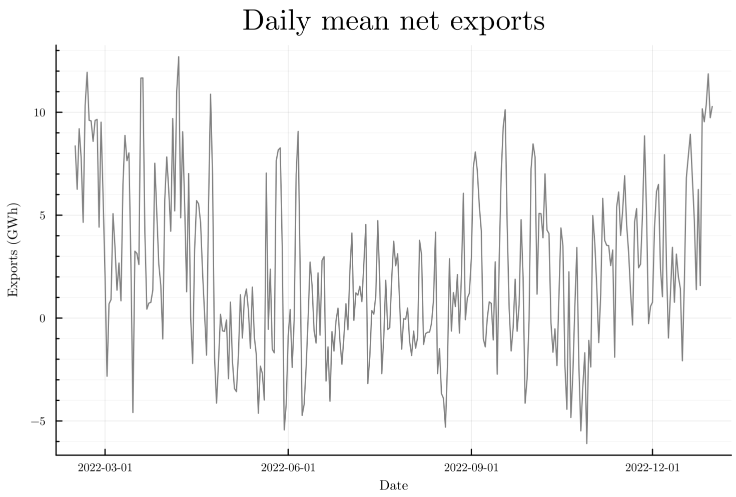
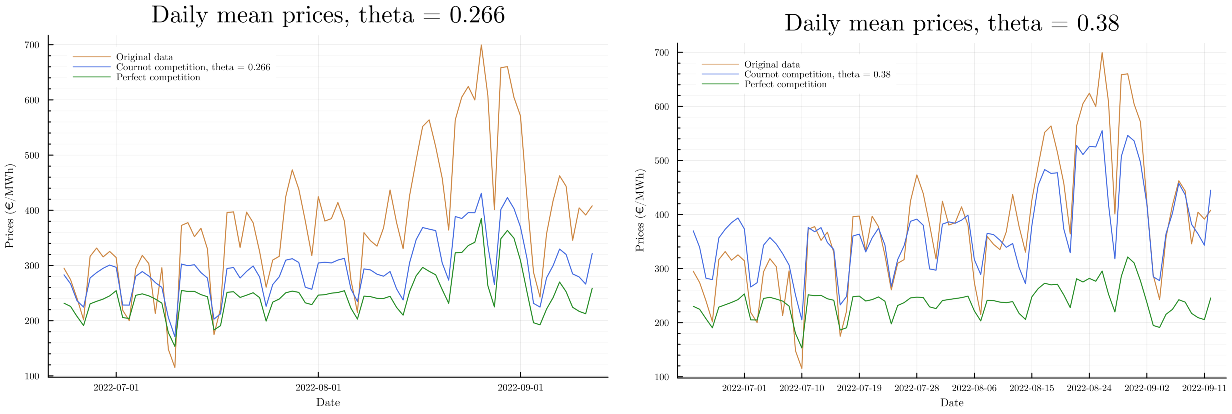


Figure 12: Quantity of exports over the year

Additional to equilibrium effects of increased exports, less competition from neighboring countries could also provide a more favourable environment for price increases due to market power. In their study, Lise et al. (2006) find that higher competition from neighboring countries lowers electricity prices as it limits the extent to exercise market power. In our case the opposite effect could happen.

Despite accounting for drivers of electricity prices like the changes of gas and CO_2 prices as well as exports during that period, the model is still unable to explain the high price surges. An increase in the exploitation of market power could be one possible reason for the price increases.

Building on the hypothesis that the conditions during the summer months might have given more room for large companies to exercise market power, we run the model for only the summer months and find that the optimal fit is reached for $\theta = 0.38$. Figure 13 shows that with a higher θ, the Cournot model provides a good fit for high prices during the summer months. This leads to the hypothesis that firms' ability to exercise market power may not be constant over time. Future research should explore a dynamic θ that varies between different times throughout a year and even within a day.



(a) Daily mean prices in summer months with $\theta = 0.26$ *(b) Daily mean prices in summer months with* $\theta = 0.38$

Figure 13: Summer months with optimal θ *fit for the whole period or just summer months*

6 Discussion and Policy Implications

6.1 Discussion

As described in Section 5 we observe that a model with market power simulated as Cournot competition performs best at describing the observed prices for the year 2022 within the German day-ahead wholesale electricity market. Comparing it to our competitive benchmark and robustness checks we calculate Price-Cost Margins, extra profits of firms and the per capita costs from the abuse of market power through RWE, EnBW, LEAG, Vattenfall and Uniper. Beingaware of our model limitations, the absolute numbers should not be overstated but rather be seen as indicative.

Simplifications of our model could introduce a bias in our results. For example Reguant (2014) shows that when including start-up costs into an electricity market model, which we do not include, the extent of observed market power could decrease. We also abstract from transmission constraints, which could have influenced prices in the observed period as well and should be implemented in future research.
Nevertheless, we run multiple robustness checks that include a substantial markup to account for unobserved costs of producers and find that the model with market power consistently provides the best match for the observed prices and quantities.

In Section 5.6 we find that the extent of market power might have been different across the times of the year, depending on the demand, exports and also the supply of renewables. We accounted for the change in market power depending on the level of demand by constructing the IO-measures in Section 5.5 only for hours where demand is above 55 GWh. Further research should look deeper into the possibility of a dynamic θ over time depending on additional market characteristics, which could increase the fit of the model.

6.2 Policy Implications

In their market report for the year 2022 the German competition authority raised the concern that electricity generating firms in Germany abused their market power to raise prices above competitive levels (Bundeskartellamt, 2023). We simulate the German market with and without market power and find that the model with market power performs better at explaining the observed prices. Even though this evidence may not hold in court due to model limitations, it provides an estimate for the extra costs that the abuse of market power might bring to consumers. As electricity is a basic good, consumed by all citizens of Germany, it is important to countervail market power and avoid excessive pricing strategies.

During the energy crisis 2022, German electricity consumers suffered through high electricity prices, while electricity producers made large profits. This fuelled the public debate about an excessive profits tax. For the upcoming European elections an excessive profit tax is now part of the election proposal of the political party "Die Linke" (Die Linke, 2024). Abstracting from the political views of the party and focusing on our calculated extra profits firms made through the abuse of market power, we can support this proposal as a short run policy implication. The tax revenue could compensate state-aid given to consumers struggling during the energy crisis and also be used to support renewable energy implementation.

In the long run, the further implementation of renewables will decrease overall market concentration (Brunekreeft et al., 2016). However, the German competition authority raises concerns that the market concentration in the thermal power plant sector increases, which will further increase the possibility of abusing market power in the future (Bundeskartellamt, 2023). Therefore it is important to think of possible ways of reducing market power going forward. One way of reducing this market power is by reforming the structure of the electricity market, e.g. as proposed by Fabra (2023), who suggests to structure part of the market based on regulator backed long-term contracts, which would introduce competition in the bidding process for contracts and thus limit the opportunities for large companies to exercise market power. Other approaches in the public debate in Germany include initiatives like "RWE & Co Enteignen", who aim for a fundamental restructuring of the German electricity market and removing the price setting authority from large companies (RWE & Co enteignen, 2023). Further research should investigate these alternative market designs and quantify their impact from a scientific standpoint.

7 Conclusion

Analysing what are the drivers behind the record high electricity prices in Germany during the energy crisis in 2022, we show that price increases cannot be sufficiently explained by higher input costs. Being the first to apply a model proposed by Bushnell et al. (2008) to the German market, we extend existing literature on the electricity market in Germany. We show that additional to higher input costs, market power was a decisive factor for price increases. Our results substantiate concerns about the abuse of market power through RWE, EnBW, LEAG, Uniper and Vattenfall (Bundeskartellamt, 2023) and may give rise to policy discussions on how to prevent additional price increases through the exercise of market power in order to avoid adverse effects on consumers and overall welfare losses.

Comparing the competitive prices during high demand hours to the corresponding prices of the model with market power, we find that prices were on average 17.45 % higher than they would have been if firms did not exercise market power. Being aware of our model's limitations, we conduct robustness checks to account for factors not included in our model. We find that price-cost margins average at 11.45 % across all simulations. Firms benefited from the higher prices through extra profits of 7.45 bn € during the year 2022, while the average cost to consumers amounts to 90.92 € per capita during the observed period. This is of particular importance given that consumers already suffered higher expenses during the energy crisis.

Further research should include start-up costs and transmission constraints into the model. Additionally, the possibility of a dynamic conjectural variation parameter over time could be explored. Alternative market designs that limit the possibility of exercising market power should be investigated further.

A Appendix

A.1 Cournot Setup

Building on economic theory we assume that, when markets are not perfectly competitive, firms exercise market power by choosing quantities in order to maximize profits as in the Cournot oligopoly framework (Cowling and Waterson (1976), Bushnell et al. (2008)). In this section, we show a static Cournot setup assuming identical firms in order to illustrate the interpretation of θ.

From (1) we derive the inverse demand function where Q refers to the total quantity:

$$p(Q) = \frac{a - Q}{b}$$

Firm's maximize their profits by choosing quantities as in:

$$\max_{q_i} \ \pi_i = \frac{a - Q(q_i)}{b} \ q_i - C(q_i)$$

where the total quantity Q varies with the quantity supplied by the individual firm i. Taking first order conditions:

$$\frac{\partial \pi_i}{\partial q_i} : p(Q) - \frac{1}{b} \ \frac{\partial Q}{\partial q_i} q_i - \frac{\partial C(q_i)}{\partial q_i} \geq 0$$

In order to define the markup term, we need to define how the total quantity changes with the supply of firm i. In the symmetric Cournot model, all firms have equal best response functions, so $Q = \sum_i q_i$ and $\frac{\partial Q}{\partial q_i} = 1$, leaving the markup term as $\frac{1}{b} \ q_i$. In a monopoly, $Q = q^M$, thus $\frac{\partial Q}{\partial q_i} = 1$ and the markup equals $\frac{1}{b} \ Q$. Under perfect competition, $\frac{\partial Q}{\partial q_i} = 0$, so there is no markup. However, making market conduct more flexible, we follow Graf and Wozabal (2013) and assume that firms choose quantities depending on their beliefs about the best responses of other firms, described by the reaction function R_{-i}:

$$Q(q_i) = R_{-i}(q_i) + q_i$$

This lets us rewrite the markup term as $\frac{1}{b} \ (R'_{-i} + 1) \ q_i$. Setting $(R'_{-i} + 1) = \theta$ we can rewrite the FOC as:

$$\frac{\partial \pi_i}{\partial q_i} : p(Q) - \theta \ \frac{1}{b} \ q_i - \frac{\partial C(q_i)}{\partial q_i} \geq 0$$

which defines the markup as we incorporate it in our model. The conjectural variation parameter θ thus describes the companies beliefs (conjecture) about how the quantity supplied by rivals reacts to changes in their own quantity, i.e. how much total quantity changes with

q_i. $\theta = 1$ recovers the markup under static Cournot competition. If the market is not a monopoly, so $q_i < Q$, but the markup is higher than the one expected under Cournot competition and tends towards the monopoly markup $\frac{1}{c}Q$, θ can be larger than 1. Under perfect competition, total quantity is unaffected by the supply of firm i, so $Q = R_{-i} + q_i = -q_i + q_i$ resulting in $\theta = 0$. Higher values of θ indicate the belief that rival's quantities are more affected by variations in the own quantity, indicating a less competitive market.

A.2 Model Calibration

Firm	**Energy Source**	**Capacity**	**Emission Factor**	**MWhin to GWhout**	**c1**	**c2**
EnBW	Hard coal	3.996	987.532	2308.09	2025.37	116.866
EnBW	Lignite	0.875	1170.06	2515.09	2515.09	0.0
EnBW	Natural gas	1.46155	589.776	2658.73	287.904	2098.82
EnBW	Oil	0.718	770.191	2905.46	2379.06	1192.37
EnBW	Waste	0.0732	0.0	3030.3	3030.3	0.0
LEAG	Lignite	6.662	1170.06	2532.47	2398.17	33.1848
LEAG	Natural gas	0.1835	589.776	2879.95	2854.07	234.213
RWE	Hard coal	0.7637	987.532	2173.91	2173.91	0.0
RWE	Lignite	8.981	1170.06	2990.23	1830.82	191.618
RWE	Natural gas	3.836	589.776	2401.3	1652.4	281.959
RWE	Waste	0.065	0.0	3030.3	3030.3	0.0
Uniper	Hard coal	2.902	987.532	2685.59	2320.97	198.504
Uniper	Lignite	0.9	1170.06	2561.48	2561.48	0.0
Uniper	Natural gas	1.614	589.776	2238.39	1231.11	1023.15
Uniper	Oil	1.418	770.191	2881.98	2676.04	192.227
Vattenfall	Hard coal	2.253	987.532	2380.75	1891.98	293.977
Vattenfall	Natural gas	1.041	589.776	2413.41	1335.77	1383.82
Vattenfall	Oil	0.319	770.191	3229.11	2954.63	1073.76
Vattenfall	Waste	0.053	0.0	3030.3	3030.3	0.0
other	Hard coal	10.9911	987.532	2515.09	1911.93	95.828
other	Lignite	0.63102	1170.06	2712.92	2123.12	1809.05
other	Natural gas	15.2112	589.776	2385.69	1279.75	101.567
other	Oil	1.1979	770.191	2760.51	2398.48	531.792
other	Other fossils	0.0754	0.0	2635.73	1248.8	23627.4
other	Waste	1.36881	0.0	3030.3	3030.3	0.0

Table 2: Firm portfolios with data on thermal energy sources and their properties. Firm "other" represents the aggregate of fringe suppliers

A.3 Model Codes

HTML files of our datacleaning and model codes are available under this link:
Fladung_Saile_Codes

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