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Julian Bergler, Sven Heim, and Kai Hüschelrath

Zentrum für Europäische
Wirtschaftsforschung GmbH

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STRATEGIC CAPACITY WITHHOLDING THROUGH FAILURES IN THE GERMAN-AUSTRIAN ELECTRICITY MARKET

Julian Bergler[†], Sven Heim[‡] and Kai Hüschelrath[§]

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Abstract

In electricity day-ahead markets organized as uniform price auction, a small reduction in supply in times of high demand can cause substantial increases in price. We use a unique data set of failures of generation capacity in the German-Austrian electricity market to investigate the relationship between electricity spot prices and generation failures. Differentiating between strategic and non-strategic failures, we find a positive impact of prices on non-usable marginal generation capacity for strategic failures only. Our empirical analysis therefore provides evidence for the existence of strategic capacity withholding through failures suggesting further monitoring efforts by public authorities to effectively reduce the likelihood of such abuses of a dominant position.

Keywords Antitrust Policy, Market Power, Auctions, Electricity, Withholding

JEL Class L94, L12, L41, K21

[†] University of Mannheim, Address: L7, 3-5, D-68034 Mannheim, Germany.

[‡] ZEW Centre for European Economic Research, Competition and Regulation Research Group and MaCCI Mannheim Centre for Competition and Innovation, Address: P.O. Box 10 34 43, D-68034 Mannheim, Germany.

[§] ZEW Centre for European Economic Research, Competition and Regulation Research Group and MaCCI Mannheim Centre for Competition and Innovation, Address: P.O. Box 10 34 43, D-68034 Mannheim, Germany, E-Mail: hueschelrath@zew.de; University of Mannheim, L7, 3-5, D-68131 Mannheim, Germany. *Corresponding author.* We are indebted to Dominik Schober, Tobias Veith and Oliver Woll for useful discussions and remarks.

1 Introduction

Strategic behavior – defined as set of actions a firm takes to influence the market environment so as to increase its profits[1] – is a common occurrence in markets with a rather small number of firms being able to observe each other's actions. Although strategic behavior is generally expected to lead to prices above marginal costs, only certain forms are considered likely to lead to clear net welfare losses and are thus banned by existing competition laws. Examples include various forms of abuses of a dominant position such as predation, certain rebate schemes or raising rival's costs strategies.

Since the deregulation of significant parts of electricity markets in many countries around the world, operators have been quite innovative in applying various forms of strategic behavior aiming at increasing profits, however, with potentially negative net effects on overall welfare (see generally Stoft, 2002). An intensively discussed form of such strategic behavior is 'capacity withholding' which makes use of the fact that the supply schedule typically is convex while demand is unresponsive to price signals in the short-term. Hence, whenever demand is high, a small reduction in supply substantially increases the marginal price and – because electricity markets are generally organized as uniform price auctions – the price all operators receive. By strategically removing a fraction of their operating capacity from the market (e.g., by pretending a sudden failure of a generation unit), multi-unit plant operators expect that the correspondingly higher prices realized for the remaining operating units offset the lost revenues from the (strategically) removed capacity and thus lead to a net increase in profits.

In this context, we use a unique data set of failures of generation capacity in the German-Austrian electricity market to investigate the relationship between electricity spot prices and generation failures. Differentiating between strategic and non-strategic failures, we find a positive impact of prices on non-usable generation capacity for strategic failures of hard coal as well as (partly) gas-fueled plants only. Our empirical results are therefore consistent with existing theoretical research which has identified market price manipulations through (mocked) failures – so called physical capacity withholding – as potentially rational behavior of multi-unit plant operators in electricity markets. From a policy perspective, our findings suggest (further) monitoring efforts by public authorities to effectively reduce the likelihood of such abuses of market power.

[1] Carlton and Perloff (2000), pp. 332f.

The remainder of the paper is structured as follows. The following second section introduces into the theoretical concept of strategic capacity withholding and reviews empirical evidence from different national electricity markets. The subsequent third section begins with a general characterization for the German-Austrian electricity market in Section 3.1 followed by a more specific discussion on the relevance of strategic capacity withholding in this particular market as part of Section 3.2. Our empirical analysis of a possible relationship between electricity prices and generation failures is presented in the fourth section. While Section 4.1 describes the construction of the data set and discusses the descriptive statistics, Section 4.2 develops our empirical strategy and presents our empirical results. Section 5 concludes the paper.

2 Strategic Capacity Withholding – Theoretical Concept and Empirical Evidence

We first provide an introduction of the theoretical concept of strategic capacity withholding in Section 2.1, followed by a brief review of existing empirical research on this form of strategic behavior in Section 2.2.

2.1 Theoretical Concept

The possibility and profitability of strategic behavior is closely tied to certain market- and firm-related preconditions. From a market perspective, the success of strategic behavior crucially depends on how well a certain strategy is taking advantage of, first, general demand- and supply characteristics and, second, the implemented market design (including a possible regulatory oversight). From a firm perspective, a certain degree of market power is usually needed to be able to successfully apply strategic moves.

Electricity as product generally has many characteristics which make an application of various forms of strategic behavior likely. From a market perspective, a lack of real-time pricing and demand side participation leads to inelastic short-term demand for both industrial and residential consumers. From a firm perspective, especially generation markets are often characterized by the presence of few but large multi-unit plant operators which are generally able to successfully implement strategic moves. Typically, their respective generation systems consist of several types of units with some being characterized by low marginal costs but low flexibility (e.g., renewables, nuclear or lignite plants) and some by high marginal costs but higher flexibility in use (e.g., hard coal or gas-fueled plants). While the former are typically covering the base load, i.e., minimum demand, the latter are activated gradually to the degree rising demand makes this necessary. Therefore, the supply curve is typically convex.

The design of many (wholesale) electricity markets allows producers two main possibilities to trade their product: 'long- and medium-term' or 'short-term'. The typically largest part of expected demand is traded via long- and medium-term contracts 'over-the-counter' from several years to months prior to supply. Short-term contracts come into play when actual demand can be estimated more precisely. These contracts are then typically traded at a power exchange, the so-called spot market for electricity. Subdivided further into the day-ahead market and intraday trading, the former aims at optimizing liquidity in the market while the latter ensures the possibility to react to specific incidences closer to real-time.

Focusing on 'short-term' day-ahead markets in the remainder of this section, the majority of these markets are organized as uniform-price auction or last-price auction (see Newbery, 1995), i.e., market participants submit their bids and asks and the operating counterparty sets a clearing price that all participants receive or pay, respectively. This market design implies that buyers who bid more than the clearing price have to pay less than they actually would. By the same logic, suppliers that offered their output for less than the clearing price experience a profit[2] (see Cramton and Stoft, 2007).

As uniform price auctions are established at most power exchanges all over the world[3], there is a large amount of academic literature analyzing electricity markets with uniform-price auctions[4] in general and 'suspicious' developments such as unexpected temporary price rises in particular (see, e.g., Kwoka and Sabodash, 2011). These developments raised concerns about the abuse of market power – first and foremost

[2] As a consequence, in an electricity market environment, operators of power plants fueled with low-cost resources experience profits (stimulating further investments in these types of production technologies; see Cramton and Stoft, 2007).

[3] The UK is the most prominent exemption where the New Electricity Trading Arrangements (NETA) in 2001 introduced the pay-as-bid auction as allocation mechanism. A key driver for this market design reform in England and Wales was the belief of the British regulatory authority in charge, OFGEM, that uniform auctions are more subject to strategic manipulation by large traders than pay-as-bid auctions (see, e.g., Evans and Green, 2003). From an academic perspective, on the surface, such a market design would indeed eliminate the profitability of strategic capacity withholding as power plants do not profit from a spontaneous unavailability of another power plant. However, as shown by Kahn et al. (2001) or Heim and Götz (2013), withholding strategies are also possible in pay-as-bid auctions under certain market conditions.

[4] Another reason is that uniform price auctions offer advantageous properties for algebraic analysis compared to pay-as-bid auctions.

with respect to forms of collusive behavior but also with respect to applications of particular unilateral strategies including abusive capacity withholding.

Generally, the capacity withholding strategy makes use of the particular characteristics of electricity markets in general and uniform-price auctions in particular. Given the inelastic demand and applying uniform-price auctions, all operators receive the same price (per unit of output) which is determined by the costs of the marginal plant that is just needed to satisfy demand. In such an environment a small reduction in supply causes large price increases whenever demand intersect with the supply curve at a sufficiently steep part. By strategically removing a fraction of their operating capacity from the market, operators expect that the correspondingly higher prices realized for the remaining operating units offset the lost revenues from the (strategically) removed capacity. Eventually, capacity withholding is expected to lead to higher profits for the multi-unit plant operators at the expense of a reduced consumer surplus. Although the deadweight loss is expected to be small or even non-existent due to the low demand elasticity, efficiency losses are nevertheless created by a suboptimal use of the existing generation systems with baseload units being replaced (for strategic reasons) by a less efficient marginal technology.

Although the idea behind a capacity withholding strategy is straightforward, its successful practical implementation is tied to certain conditions. First, capacity withholding by definition demands a multi-unit operator as only the existence of multiple units provides the possibility that the (additional) revenues generated by the still operating units surpasses the lost revenue from the withheld units. Second, in addition to multiple units, a certain market share (or market power, respectively) is sometimes mentioned as additional precondition for a successful application of capacity withholding strategies. However, although there are no serious doubts that the attractiveness of such a strategy increases with the number and size of plants of a certain operator – leading to a decrease in the minimal price that is needed to profitably apply a withholding strategy – the general method can also be successfully applied by smaller multi-unit plant operators units without a significant overall market share (see, e.g. Cabral, 2002, Dechenaux and Kovenock, 2007, Kwoka and Sabodash, 2011, or Fogelberg and Lazarczyk, 2014).

Turning from the general concept to the implementation of the capacity withholding strategy, the academic literature distinguishes between ‘economic withholding’ and ‘physical withholding’ (see Joskow and Kahn, 2002). Economic withholding – also known as hockey stick bidding – refers to a strategy where a supplier offers part of its capacity at an extremely high price thus moving it to the very right of the supply curve. Consequently, a part of the overall supply curve would shift to the left causing the desired price increase of a capacity withholding strategy. Although theoretically sound and workable, economic withholding faces the key challenge that it is relatively easy to detect by market surveillance authorities, e.g., by comparing the respective bid curves of a suspicious operator either over time or between different operators (see Heim and Götz, 2013).

Due to these challenges in hiding economic capacity withholding strategies from public authorities, the recent literature concentrates on physical capacity withholding strategies as part of which the respective capacity is completely taken out of the market and thus achieve the desired shift of the supply curve to the left. Generally, there exist different reasons why capacities are temporarily non-usable (see Joskow and Kahn, 2002). While scheduled non-usabilities, i.e., outages that are announced well in advance, are likely to reflect regular maintenance activities, unscheduled non-usabilities reported shortly before or after the beginning of the outage rather refer to acute failures of the respective units. Because information on the market situation increases as the time of generation approaches – which is crucial for profitable execution of withholding strategies – particularly unscheduled non-usabilities through pretended acute failures appear to be a suitable capacity withholding strategy. In our empirical analysis below we will therefore differentiate between the possible impact of electricity prices on non-usable generation capacity from failures with and without the potential to successfully apply strategic capacity withholding.

2.2 Empirical Evidence

In the following, we review several seminal empirical papers on the issue of capacity withholding in the national electricity markets of England and Wales, the United States and Sweden. Studying strategic behavior in the electricity market in England and Wales, Wolfram (1998) finds indications for strategic bidding when prices are high. In particular, she provides evidence consistent with the presence of economic capacity withholding through high bids for marginal units. Wolfram further shows that bigger suppliers were more active in applying such strategies indicating that a large market share facilitates strategic capacity withholding. Wolak and Patrick (2001) also investigate the electricity market of England and Wales. They argue that, given the market framework at the time, the two major market suppliers can increase their profits by choosing which part of their capacity they declare as available. Although partly dependent on factors not completely under their control, Wolak and Patrick (2001) find evidence for the (temporary) existence of strategic capacity withholding behavior.

Turning to empirical evidence from the United States, Joskow and Kahn (2002) analyze the 2001 California electricity crisis and specifically investigate whether forced outages contributed to the dramatic prices increase experienced at the peak of the crisis. The authors find evidence for “a substantial gap between maximum possible levels of generation and observed levels in those hours identified as economical for all in-state generation” (Joskow and Kahn, 2002, p. 29). Although the data used for the analysis does not allow a deeper analysis of potential withholding behavior, they conclude that “there is sufficient empirical evidence to suggest that the observed prices reflect suppliers exercising market power” (Joskow and Kahn, 2002, p. 29).

In their empirical analysis of the New York wholesale electricity market, Kwoka and Sabodash (2011) aim at investigating whether identified temporary and unexpected rises in the price – so-called price spikes – can be seen as an indication for strategic capacity withholding activities. Focusing on possible differences in quantities offered in the market, they argue that any evidence indicating that suppliers offer less electricity when peak prices are forecasted than under ordinary conditions would represent “a divergence from normal profit-maximizing business behavior” (Kwoka and Sabodash, 2011, p. 298). They find clear evidence of such behavior for the largest bidders in the market who seem to have conducted both physical capacity withholding and some kind of economic capacity withholding aiming at increasing the market price. While all these studies analyze withholding strategies in uniform-price auctions, Heim and Götz (2013) also find evidence for an application of such strategies in pay-as-bid auctions (for the case of the German market for reserve capacity).

Last but not least, Fogelberg and Lazarczyk (2014) investigate strategic capacity withholding in the Swedish day-ahead market. Using a data set of all power plant outages (exceeding a certain dimension), they aim at analyzing whether price developments have an influence on failures of generating units which could be seen as evidence for the existence of strategic capacity withholding. Furthermore, the authors expect that, first, in accordance with the theoretical considerations above, marginal units rather than baseload units are predominantly abused to exercise such capacity withholding strategies. Second, Fogelberg and Lazarczyk (2014) identify a different type of capacity withholding that refers to the delayed restart of units after a shut-down. In particular, an operator could for example delay the restart of a power plant when prices are high because it expects the price to significantly decrease once the power plant is back in production.

Given these hypotheses and applying a detailed data set on failures in the Swedish market, Fogelberg and Lazarczyk (2014) find a significant positive relationship for all fuel types and for the market's marginal units. A split of reports in new failures and follow-up failures shows that the effect is slightly larger for follow-up failures providing evidence for both the theory about failures in general and the role of follow-up failures in particular. As part of our empirical analysis below, we will investigate whether comparable empirical evidence on capacity withholding can be found for the German-Austrian electricity market.

3 The German-Austrian Electricity Market and the Relevance of Strategic Capacity Withholding

Important preconditions for a meaningful empirical investigation of the role of strategic capacity withholding is, first, a deeper understanding of the design of the German-Austrian electricity market in general (Section 3.1) and, second, an overview of prior discussions on the relevance of strategic capacity withholding in this market in particular (Section 3.2).

3.1 The German-Austrian Electricity Market

According to 2013 Eurostat data[5], the fully integrated German-Austrian electricity market[6] accounts to roughly 21 percent of total final energy consumption in the European Union. With about 581 TWh of consumed electricity, the market was substantially larger than the national markets in the runner-up countries France (439 TWh), the UK (317 TWh), Italy (287 TWh) and Spain (232 TWh).

Generally, the German-Austrian electricity market is characterized by the same well-known demand- and supply-side specificities of electricity markets already sketched in Section 2.1 above. On the demand side, residential or industrial demand for electricity is

5 http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_production,_consumption_ and_ market_overview/de (last accessed on 8 January 2016)

6 Although different nations, the electricity markets of Germany and Austria are fully integrated showing "… no bottlenecks at cross-border interconnectors … and the two countries comprise a single market and price territory on EPEX" (German Federal Cartel Office, 2011, p. 6).

highly price-inelastic – despite recent increases in demand management appliances – and fluctuates over the day with the peak period defined from 8am to 8pm (and a reduced demand over the weekends). Average prices in the winter are higher than in the summer mainly due to the use of heating facilities (and the limited role of air conditioning in the summer).

On the supply-side, Figure 1 below shows the merit order for the German-Austrian market in 2013. It begins on the left-hand side with a significant (and further increasing) share of 'must-take' renewables followed by nuclear, lignite and (newer) hard coal power plants.[7] In 2013, these technologies together were sufficient to cover the average demand for electricity in Germany and Austria. Peak demand coverage, however, demanded the additional operation of more inefficient (older) hard coal plants as well as (more flexible) gas- or even oil-fueled plants located at the right of the merit order due to their higher marginal costs of production.

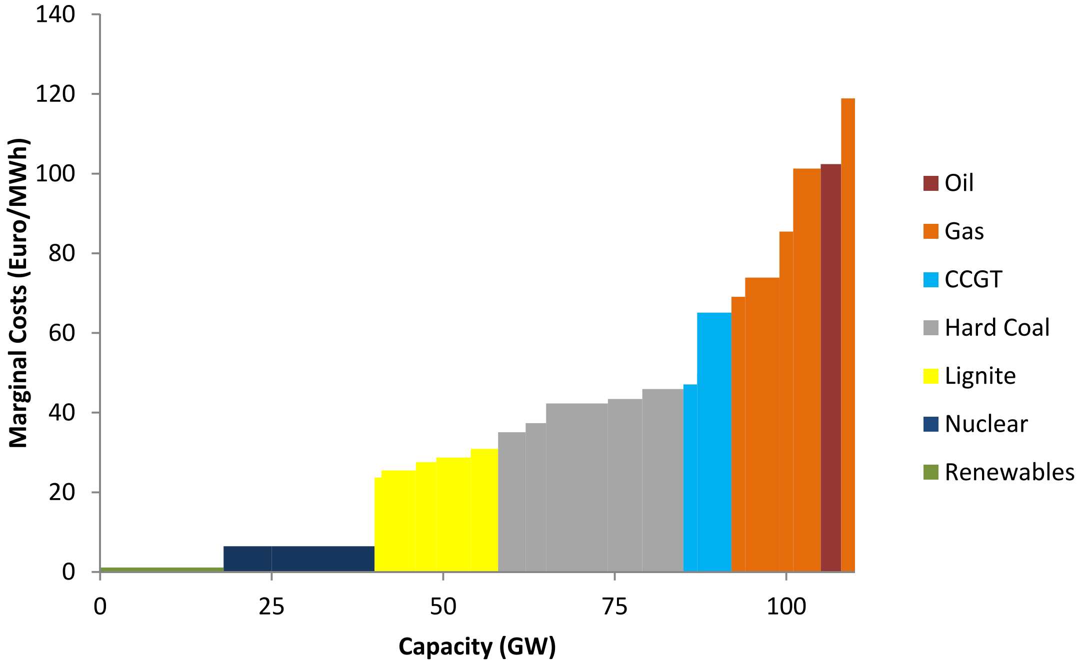

Figure 1: Merit Order in the German-Austrian Electricity Market in 2013

Note: Constructed from technical data using fuel costs and efficiency factors of each power plant in the German-Austrian electricity market

Although a large fraction of electricity in the German-Austrian electricity market is allocated 'over-the-counter' via long-term contracts, roughly one third of the overall

7 Due to promotional schemes, renewables benefit from unlimited priority feed-in into the grid regardless of demand.

demand is traded on the day-ahead spot market called EPEX SPOT[8] which handles the spot markets for Austria, Germany, Switzerland and France. EPEX SPOT basically offers market platforms for the day-ahead auctions and continuous intraday trading. These different markets offered by EPEX SPOT should be interpreted as complements rather than substitutes as the day-ahead market is thought to optimize liquidity in the market while the intraday trading ensures the possibility to react to specific incidences closer to real-time. Even though up-to-date information on the profitability of withholding strategies will be available in the intraday market, there are at least two reasons which make an application of withholding strategies in this market unlikely: first, as the intraday market works via bilateral trading instead of being organized as auction there is no single clearing price (which prevents the profitability of withholding capacity) and second, the market only has the task to smooth short-term deviations between supply and demand and therefore only a small amount of capacity is traded intraday (limiting the profitable execution of withholding strategies). Thus, as only the day-ahead market provides an environment potentially suitable for strategic capacity withholding, we limit our further discussion and analysis to this particular market.

In uniform price auctions, all successful bidders receive the same price per unit of output which is determined by the price of the marginal plant that is just needed to satisfy demand. Bids basically contain the amount of power demanded or supplied for a certain timeframe and the corresponding willingness to pay. This timeframe can either be an individual hour or a block of hours on the next day. Having the merit order concept in mind, it appears obvious that a power plant with lower marginal cost would bid a lower price for its generated electricity with the aggregated supply curve eventually reflecting the merit order of the market. In the German-Austrian market, the bids have to be submitted until 12 pm on the day before. The system then aggregates the orders to demand and supply functions. The intersection of the resulting curves finally determines the traded quantity and the market price.

As part of their market surveillance activities, EEX collects and publishes – via its transparency platform[9] – detailed information on both scheduled and unscheduled non-usabilities of all reported power generation generating units of 100 MW or more lasting

[8] EPEX SPOT has been created after the merger of Powernext SA in France and the European Energy Exchange (EEX) AG in Germany. Under the new EPEX organization, EEX provides both general market data and further up-to-date market information regarding the EPEX SPOT market.

[9] http://www.eex-transparency.com/homepage/power/germany/production/availability/non-usability (last accessed on 8 January 2016).

for a minimum time of one hour. The information provided by the platform will be of key relevance for our empirical analysis in Section 4 below.

3.2 The Relevance of Strategic Capacity Withholding

The uniform price auction applied at the EPEX (formerly EEX) power exchange generally provides the opportunity for capacity withholding strategies and their actual implementation[10] – by a dominant multi-unit plant operator – would constitute an abuse of a dominant position within the meaning of Article 102 of the Treaty on the Functioning of the European Union (TFEU) and of Section 19 (1) of the German Act against Restraints of Competition (ARC). Already in 2002, the European Commission initiated abuse proceedings against the four large energy providers in Germany (E.ON, RWE, EnBW and Vattenfall) accusing them of price manipulations at the EEX in general and capacity withholding in particular. Although all proceedings were eventually closed without deciding on the question whether capacity withholding strategies were actually applied, in the case of E.ON, the Commission (in November 2008[11]) reached a concession agreement that forced the energy provider to the sale of 5.000 MW of generation capacity (and their supergrid) aiming at reducing its market power.[12]

Parallel to (and after) the investigation by the European Commission, the topic gained in importance in Germany, e.g., reflected in political initiatives (particularly by the Green Party demanding additional market monitoring activities), newspaper articles (see, e.g., Schumann, 2009, or Dämon, 2011), articles published in German law journals (see, e.g., Becker, 2008, Jahn, 2008, and Jungbluth and Borchert, 2008), commissioned reports on the role of market power in German electricity wholesale markets in general and the role of capacity withholding in particular (see, e.g., Swider et al., 2007, von Hirschhausen et al., 2007, or Fouquet et al., 2011) as well as several purely academic studies (see, e.g., Müsgens, 2006, or Schwarz and Lang, 2006).

While the German Federal Cartel Office refrained from investigating the presence of capacity withholding strategies in parallel to the European Commission, the authority

[10] As the large electricity providers in Germany are prohibited by law to set prices above marginal costs, the incentive to apply strategic capacity withholding strategies – as generator of additional revenue – is increased further.

[11] COMP/39.388 Deutscher Stromgroßhandelsmarkt and COMP/39.389 Deutscher Regelenergiemarkt.

[12] The proceedings against the other three large energy providers were closed in October 2009 without the imposition of any concessions. For RWE and Vattenfall, no sufficient evidence on capacity withholding activities were found and in case of EnBW the absence of a dominant position in the market already foreclosed the imposition of any concessions or fines.

later considered the existing evidence as insufficient to initiate formal abuse proceedings. However, it decided to investigate the issue as part of a broader sector inquiry into electricity generation and wholesale markets whose results were published in January 2011 (see German Federal Cartel Office, 2011, for an English summary). Interestingly, mainly concentrating on physical capacity withholding[13], the authority collected detailed data from the respective power plant operational managements of the four large energy providers in Germany aiming at determining (retrospectively) the optimal operation of each individual electricity generating unit.[14] After cleaning the data for non-usabilities caused by reasons other than (potential) capacity withholding[15], the respective optimized operation values were compared to the actual operation of each unit thereby establishing the extent to which the units were not operating (although they should have in a competitive environment).

Although the application of the algorithm was eventually able to identify a limited amount of unutilized capacity, the authority concluded that "… the non-operation of profitable power plants identified in the present inquiry is too limited to initiate specific abuse proceedings with respect to the period examined" (Federal Cartel Office (2011), p. 13). In particular, the following alternative explanations for the observed amount of unutilized capacity were mentioned: (1) intraday market trading activities, (2) the general uncertainty operators face when optimizing generation capacity (which cannot be taken into account as part of the retrospective assessment done by the authority), (3) the development of more complex bidding strategies, and (4) remaining technical restrictions (beyond the ones already excluded in the beginning of the analysis). In sum, the impossibility to differentiate clearly between (anti-competitive) capacity withholding behavior and other types of (pro-competitive) behavior in the observed market conduct foreclosed the initiation of abuse proceedings against the large energy providers (see also Swider et al. (2007) for a general discussion of the challenges of empirically identifying capacity withholding strategies in real markets).

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[13] The Federal Cartel Office assumes an abuse of market power by physical capacity withholding "… where an undertaking in a dominant position, without any objective reason, does not offer electricity from capacities actually available which could be sold at a price at or above its respective short-term marginal costs" (Federal Cartel Office (2011), p. 10).

[14] The optimization criterion here is the contribution margin of each individual electricity generating unit over a period of one year.

[15] In particular, the Federal Cartel Office included technical limitations, such as routine maintenance or unplanned power plant blackouts, minimum operational and minimum standstill times, grid restrictions and the provision of control and reserve capacity.

Despite the fact that the suspicions of strategic capacity withholding have so far not led to a conviction as part of formal abuse proceedings on either the European or the national level, the intensive discussions in both academia and practice on the relevance of market power abuses in energy markets certainly contributed to the creation of a general European legal framework for monitoring wholesale energy markets in order to prevent insider trading and market manipulation – the so-called REMIT Regulation – and its specific implementation in Germany through the passing of the 'Act on the creation of a market transparency body for electricity and gas wholesale trading'. The act provides the legal basis for a more extensive monitoring of wholesale electricity and gas markets by the so-called 'market transparency unit for wholesale electricity and gas markets'[16] which is jointly run by the competition authority – the German Federal Cartel Office – and the regulatory authority – the German Federal Network Agency. Complementary, as already described in the previous sub-section, the EEX introduced a transparency platform – according to the REMIT standards – easing the monitoring of the respective markets and additionally providing the possibility to conduct empirical research on the issue of strategic capacity withholding through failures described in the following section.

4 Empirical Analysis

In this section, we empirically analyze the relationship between electricity prices and generation failures. While Section 4.1 describes the construction of the data set and discusses the descriptive statistics, Section 4.2 continues with the development of our empirical strategy – including the choice of instruments and the choice of control variables – and the presentation of our empirical results.

4.1 Data Set and Descriptive Statistics

The data set used in this article was constructed by merging data of different types and sources. Given our research question of a possible impact of electricity prices on generation non-usabilities, our main variables characterized in the following are failures of generating units and electricity prices (Section 4.1.1) followed by our control variables (Section 4.1.2). The descriptive statistics of our data set are presented and discussed in Section 4.1.3.

[16] More detailed information on the market transparency unit for wholesale electricity and gas markets can be found at http://www.markttransparenzstelle.de/cln_1432/EN/Home/start.html (last accessed on 8 January 2016).

4.1.1 Main Variables

Failures

Failures (i.e., non-usabilities) of generating units in the German-Austrian electricity market represent our outcome variables and were constructed by conducting several subsequent steps. First, we accessed the EEX Transparency Platform[17] which provides detailed information on both scheduled and unscheduled non-usabilities of all reported power generation units of 100 MW or more lasting for a minimum time of one hour.[18] The platform includes information on type (scheduled or unscheduled), company, facility, unit, fuel, control area, begin and expected end, limitation (MW), reason (outage or other), status as well as updates on the respective non-usability event, e.g. whether the length of the non-usability was actually shorter or longer than initially reported.

Second, we restricted our raw data set to all non-usability events in the period from 1 January 2013 to 31 March 2014. While the beginning of our observation period was determined by the fact that the data in its current form is only available from December 2012 onwards, the end of the observation period was necessary due to additional reporting requirements for several companies that were demanded from spring 2014 onwards (which led to a reduced availability of the data needed for our analysis).

Third, the fact that every update on a certain non-usability event enters the platform as new event required a substantial adjustment process of the raw data to arrive at a data set with one single entry for each non-usability. In fact, we made use of this situation and created two sub-data sets: a first one presenting the information related to the first announcement of a certain non-usability and a second one with the information related to the last update for a particular case.[19]

Based on this initial data set we construct two measures of failures as outcome variables: *Non-strategic failures* and *strategic failures*. Failures classified as *non-strategic* contain all failures we do not expect to possess any strategic potential in terms of successfully implementing a profitable capacity withholding strategy. Profitable withholding strategies require a) ex-ante knowledge of sudden price spikes and b)

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17 http://www.eex-transparency.com/homepage/power/germany/production/availability/non-usability (last accessed on 8 January 2016).

18 Limitations of at least 10 MW lasting for 15 minutes or more can be reported on a voluntary basis.

19 The comparison of the first announcements with the last updates is similar to the strategy of splitting failure reports into new reports and follow-up reports as implemented in Fogelberg and Lazarczyk (2014).

entering the market again as close as possible after the price spike. Therefore, we chose a definition where such non-strategic failures are planned and announced with a sufficiently long lead-time prior to the outage. At that point in time, we assume market information will still be too imprecise to apply strategic withholding, especially due to the large share of generation from fluctuating renewable energy sources. Furthermore, as price spikes mostly occur for a few hours only, it is reasonable to believe that outages that last longer than one day are most likely not subject to strategic capacity withholding. In sum, all failures are defined as *non-strategic* which last less than one day and are announced more than one week before the actual outage. As a plant operator can adjust the duration of a failure thereby introducing a further strategic component (e.g., through extending or shortening the failure duration conditioned on the price level at the time of the failure), we use the initially reported length of the failure at the time of the announcement rather than its actual length.

In contrast, our *strategic failures* variable contains all failures with characteristics that might enable withholding strategies. Such failures must be spontaneous reactions to certain market situations in which withholding only a small fraction of capacity is likely to cause a substantial price increase. Furthermore, such spontaneous outages must not last particularly long as a withholding strategy is typically only a profitable strategy for a few hours (due to rapidly changing load patterns). As a consequence, we only define failures as strategic if they are unannounced, i.e., they were reported after the beginning of the actual event, and last only one day or less. However, in contrast to the procedure implemented for non-strategic failures, we now measure the length of a failure by the actual rather than the initially reported length in order to take account of the possible incentives of operators to condition the length of the outage on current price levels.

Generally, we compute both strategic and non-strategic failure variables for all relevant fuel types. The application of the separate steps just characterized results in our failure data set ready to be used in the empirical analysis. Although the data set includes information on both the number of non-usable units and the number of non-usable megawatts, we will use the latter as part of our analysis – basically because the size of the respective shifts in the supply curve depend on the changes in capacity rather than the number of generating units.

Electricity Prices

The predictor variable of interest for our research question is the electricity price. For the (fully integrated) German-Austrian market, electricity price data are obtained from the EPEX server. We use the EPEX base price – a spot price index provided by EPEX which is computed as the unweighted average of hourly prices. We are aware of potential endogeneity issues as regards our key variable. An obvious reason is reverse causality as the demand curve intersects the merit order further to the right whenever a power plant would be "in merit" but is not available. This in turn increases the marginal price. In fact, this is nothing else than the actual motivation for multi-unit plant operators to withhold capacity. If this would not be the case, an application of strategic withholding strategies would no longer be possible. We therefore have to instrument for the electricity price by using the TTF Gas Price, ARA Coal Price and the ETS Carbon Price (all three obtained from Thomson Reuters Datastream). As hard coal and gas are input resources for electricity generation and the carbon emission price also causes cost shifts, rising prices in these variables are expected to cause rising electricity prices. Prices for hard coal, gas and carbon are assumed to be exogenous, given that the prices for these inputs are determined on a supra-national basis rather than being set domestically within Germany. Hard coal and gas are traded on the world market and carbon within the EU ETS which covers all 28 EU states plus Norway, Liechtenstein and Iceland. At the same time, there is no apparent reason to believe that these prices have any direct influence on power plant non-usabilities.

4.1.2 Control Variables

Complementary to our failure type outcome variables and the variable of interest – price – we include several control variables described in the next paragraphs.

System Load

Data for the system load are obtained from the ENTSO-E transparency site. Our load variable is computed as the sum of the daily average loads in Germany and Austria. As system load determines the power plants required to meet demand, i.e., the intersection of the demand and supply curve, one could initially consider it a candidate to instrument for electricity price if a perfectly inelastic demand is assumed in the short-term. However, there is also a potential relation between system load and failures: when demand is high, multi-unit plant operators have incentives to run their generating units at maximum capacity but a high demand also requires a higher flexibility (so-called cycling). Both make outages more likely. Thus, the level of load might have explanatory power for failures and, at the same time, is also related to the electricity price. However, since we instrument for price and are not particularly interested in the coefficient of load, we simply include the load variable into our model on the right-hand side.[20]

Temperature and Level of German Rivers

As many (conventional) German power plants take their necessary cooling water out of rivers, high river temperatures (above 23° Celsius) and low river levels might force them to reduce or even shut-down their electricity generation making price increases likely (see, e.g., McDermott and Nilsen (2012) for evidence from Germany). To be able to take this potential failure cause into account, we collected detailed data on daily temperatures and levels of important German rivers – covering most of the larger regions in the country – from the German Federal Waterways and Shipping Authority (WSV) supplied by the German Federal Institute for Hydrology (BfG).

We use the provided raw data to construct a German river level index.[21] A dummy variable is derived that indicates whenever this index is below the 15 percent percentile of the data series. Furthermore, a second dummy variable indicates whenever the daily average temperature of one of the regarded rivers[22] exceeds 23° Celsius.[23] This has been the case on 23 days within our observation period.

Generation of Renewable Energy

According to existing regulations in the EEG (Erneuerbare Energie Gesetz: translated Renewable Energy Act), the feed-in of renewable energy is guaranteed and renewable generation receives fixed feed-in tariffs above their low marginal costs. As a consequence, whenever these units are producing energy, they are located at the very left of the merit order pushing all other power plants to the right. This decreases the

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[20] Additionally instrumenting for load does not change our main results significantly. For these estimations, we computed a temperature index and used this index and its square to instrument for load as the relationship between electricity prices and temperatures is typically U-shaped: low temperatures increase the demand for heating and high temperatures increase the demand for cooling. The respective regression tables are available from the authors upon request.

[21] Rivers considered for the level index are: Danube, Elbe, Main, Rhine and Spree.

[22] Rivers considered for the temperature dummy are: Danube, Elbe, Main and Rhine.

[23] A temperature of 23° Celsius is the legally envisaged value that, if exceeded, forces power plants to decrease electricity generation for environment protection purposes.

residual load – the part of load served by conventional technologies – and thus squeezes the market price (the so-called *merit order effect* of renewable energies).

Furthermore, there is also a likely relation between generation from fluctuating renewable energy sources and the risk of a failure for conventional power plants. The fluctuating nature of renewable energy sources such as wind and solar demands more challenging cycling activities from conventional plant types. As a consequence, the corresponding more frequent shutdowns, restarts and the generally more flexible mode of operation could lead to a larger number of forced sudden outages (e.g., due to acute repair needs) as soon as variation in renewable generation is high.[24] We therefore include the generation from wind and solar as additional control variables into the model. The data – specifically the day-ahead forecasted generation of solar and wind generation – was downloaded from the EEX Transparency platform on a quarter hourly basis and converted into daily values.[25]

4.1.3 Descriptive Statistics

Based on the initial characterization of the variables included in our empirical analysis below, Table 1 provides the corresponding descriptive statistics including our two main failure type variables: non-strategic failures – the initially reported length of those failures that are announced more than one week prior to the beginning of the outage and last longer than one day – and strategic failures – the actual length of those failures that have been reported after the unit was unavailable (unannounced failures) and last at maximum one day. For illustration purposes we additionally report the descriptive statistics only for days were the unavailable capacity of a respective fuel type was above zero. As our failure data refers to the period from 1 January 2013 to 31 March 2014, we have added all further variables for the same observation period.

[24] Already Lefton et al. (1995) argue that ‘forced outages are typically more frequent and of longer duration in cycling units than in baseload units’ (p. 197). As discussed in Kumar et al. (2012), cycling is likely to, first, increase the need for maintenance and to, second, decrease the expected lifetime of the respective plant as the essential plant components are stressed by changing pressures and temperatures whenever the unit is started, shut down or generally not operated at the load level it was constructed for.

[25] As prices for the day-ahead market are set one day before the delivery – and actual generation data arrives too late to the market to affect day-ahead prices – we included the planned generation of renewable energy in our data set.

Table 1: Descriptive Statistics

	Mean	S.D.	Min	Max	N
Dependent Variable					
EPEX Spot Price (€)	36.93	11.24	-6.28	62.89	455
Non-strategic failures (MW) – Zeros not included					
All Fuels	1477	881	100	4472	453
Nuclear	873	572	119	1360	78
Lignite	757	478	170	2081	275
Hard Coal	616	519	100	2540	347
Gas	432	262	100	1049	271
Strategic Failures (MW) – Zeros not included					
All Fuels	407	297	100	1495	165
Nuclear	419	388	120	1210	7
Lignite	308	192	105	891	23
Hard Coal	323	233	100	1114	94
Gas	397	219	163	1001	20
Non-strategic failures (MW) – Zeros included					
All Fuels	1470	884	0	4472	455
Nuclear	150	405	0	1360	455
Lignite	457	525	0	2081	455
Hard Coal	467	523	0	2540	455
Gas	258	293	0	1049	455
Strategic Failures (MW) – Zeros included					
All Fuels	148	265	0	1495	455
Nuclear	6.44	68.23	0	1210	455
Lignite	15.57	79.68	0	891	455
Hard Coal	66.76	168	0	1114	455
Gas	17.43	92.89	0	1001	455
Control Variables					
Load (MWh)	62515	7788	43660	78813	455
Wind (MWh)	1288	949	152	4927	455
Solar (MWh)	829	579	38.84	2134	455
River Level < 15% Percentile (binary)	.15	.36	0	1	455
River Temperature >23 °C (binary)	.05	.22	0	1	455
Instruments for Price					
Hard Coal Price	81.20	4.59	73.15	90.60	455
Gas Price	26.46	2.24	20.83	39	455
Carbon Emission Price	4.75	.89	2.72	7.11	455

Notes: The table presents summary statistics for all included variables from 1 January 2013 to the 31 March 2014. *Non-strategic failures* refer to the unavailable megawatts per day that have been announced 7 days or more *before* the beginning of the outage and are unavailable for at least one day. *Strategic failures* refer to the non-usable megawatts per day that have been reported *after* the beginning of the actual failure and are unavailable for less than 1 day.

Although providing a detailed interpretation of the descriptive statistics of all variables shown in Table 1 appears dispensable, it is important to discuss the results for our failure variables in greater detail. As shown in Table 1, non-strategic failures take place virtually every day with approximately 1.5 GW capacity being unavailable on average. Failures that offer strategic potential are observed substantially less often. However, there are also large differences between the different fuel types. For example, for nuclear power plants, we only find 78 days for which we observe failures without strategic potential. Situations in which nuclear plants could theoretically be subject to withholding strategies according to our definition of a strategic failure are even less likely and observed on only 7 days in our observation period. In other words, 150 MW of nuclear power without strategic potential is unavailable on an average day, however, only 6.44 MW with strategic potential.

While the situation looks similar for lignite, it is interesting to note that the fuels typically used as marginal units show substantially higher shares of *strategic failures* than the fuel types by which the baseload units are typically run. This is most obvious for hard coal which is the marginal technology most of the time and clearly posseses the highest potential to cause a substantial price rise by forcing a change of the marginal technology from hard coal to gas through the application of a withholding strategy.[26] Although this finding might also be influenced by the higher flexibility of the respective units – causing a larger amount of unannounced failures – strategic reasons might be another explanation of this general finding (justifying a detailed investigation as part of our empirical analysis below).

4.2 Empirical Strategy and Estimation Results

Guided by the existing theoretical literature and the general presence of all preconditions for a successful implementation of capacity withholding strategies, in this section, we first describe our empirical strategy to investigate the issue of strategic capacity withholding in the German-Austrian electricity market, followed by the discussion of our estimation results. In fact, building on our separation into non-strategic failures and strategic failures introduced in Section 4.1.1 above, we are able to develop the following two main hypotheses.

Failures with a sufficiently long lead-time between announcement and failure – and a failure duration above one day – are defined as non-strategic failures. As these failures also include maintenance activities, the general aim to maximize profits suggest that these activities take place in low price periods leading to our first hypothesis.

H1: For non-strategic failures, the market price is expected to have a negative impact on the occurrence of these failures.

[26] However, also some types of gas-fueled plants might be able to generate a non-marginal price increase.

Spontaneous failures – again with limited failure duration of less than one day – are defined as strategic failures, i.e., they provide preconditions for profitable strategic capacity withholding. Strategic failures will take place when prices are high and current demand intersects at the sharply increasing right-hand part of the merit order leading to our second hypothesis.

H2: For strategic failures, the market price is expected to have a positive impact on the occurrence of these failures, especially for the marginal technologies hard coal and gas.

Our empirical approach is subdivided further into two separate approaches: our main *parametric estimation approach* comparable to Fogelberg and Lazarczyk (2014) and an additional *semiparametric estimation approach* as robustness check.

Parametric estimation approach

In implementing our main empirical approach, we apply – due to the above discussed simultaneity of failures and price – instrumental variable techniques (IV) and instrument for day-ahead prices through the gas price, the hard coal price and the carbon price. The reduced form estimation in the first stage regression has the following form:

$$P_t = \alpha_1 + \beta_t' Z_t + \delta_{1t}' RE_t + \vartheta_1 Load_t + \theta_{1t}' River_t + \varphi_{1t}' Cal_t + \nu_{1t} \tag{1}$$

Subscript *t* indicates the respective day, *RE* contains renewable energy generation from wind and solar, respectively. *River* contains river related variables: a dummy variable indicating low river levels and a dummy variable indicating river temperatures above 23° Celsius. *Load* is daily average of the system load computed from hourly values. *Cal* is a vector of calendar variables, i.e. dummies for days of the week and months. *Z* contains the instruments for price – gas, hard coal and carbon emission right price.

In the second stage, our dependent variables are the power plant failures measured in MW per day and divided into failures containing the potential to strategically withhold capacity and those without such a potential (according to our definitions from above). Since our model is overidentified, we apply an IV GMM estimation approach implementing the following structural equation in the second stage:

$$Failure_t = \alpha_2 + \beta_2 \widehat{P}_t + \delta_{2t}' RE_t + \vartheta_2 Load_t + \theta_{2t}' River_t + \varphi_{2t}' Cal_t + \nu_{2t} \tag{2}$$

To account for the fact that the unavailable capacity can basically be considered as count data we also apply an IV Poisson pseudo-maximum-likelihood specification

(PPML).[27] While we use logarithms of the failures variables for the IV GMM specification (zeros replaced by zeros) we use failure levels in the case of IV Poisson to allow a comparison of the respective coefficients as semi-elasticities. Thus, we also estimate the following Poisson model:

$$Failure_t = \exp\big(\alpha_3 + \beta_3 \widehat{P}_t + \delta_{3t}' RE_t + \vartheta_3 Load_t + \theta_{3t}' River_t + \varphi_{3t}' Cal_t \big) + \nu_{3t} \quad (3)$$

The respective regression results are presented in Table 2 and Table 3. Our instruments are sufficiently strong as the stage F-statistic clearly exceeds the critical values by Stock and Yogo (2005). The validity of the instruments is also confirmed by the Hansen J statistic as we cannot reject the null hypothesis that instruments are uncorrelated with the error term. As we also have to deal with serial correlation and heteroscedasticity, we use Newey-White standard errors for the IV GMM and Huber-White standard errors clustered by weeks for the IV Poisson specification.

In general, our estimation results provide clear support for both of our hypotheses. In the *non-strategic failures* regressions in Table 2, we find significantly negative coefficients for price for all fuel types besides lignite which remains insignificant. As discussed above, the significantly negative impact for some fuels indicate that announced non-usabilities – such as, e.g., maintenance activities – are conducted in low-price periods. In any case, it appears unlikely that announced non-usabilities play a role in terms of capacity withholding strategies and our empirical results support this view.

Turning to the results for *strategic failures*, Table 3 shows – consistent with our hypothesis 2 derived above – a significant and positive price effect for hard coal suggesting strategic withholding activities in times of high prices for hard coal plants. As explained above, this result is in line with the presence of strategic capacity withholding strategies as hard coal represents the marginal technology in the German-Austrian electricity market most of the time. Furthermore, we also find a significantly positive effect for gas plant failures in the Poisson specifications. This is most likely caused by CCGT plants rather than by gas turbines since the former is the marginal technology much more often than the latter. However, as the failure data set only provides information on the fuel type, we are unable to further differentiate between these two types of gas-fueled plants.

[27] As shown by Silva & Tenreyro (2011), Poisson is well suited to analyze data with a substantial number of zeros (as relevant in our case due to the large number of days without failures for the different fuel types).

Table 2: Non-strategic Failures (Announced failures with lead-time <7 days and failure duration>1 day; as initially reported)

	All Fuels		*Nuclear*		*Lignite*		*Hard Coal*		*Gas*	
	GMM	Poisson	GMM	Poisson	GMM	Poisson	GMM	Poisson	GMM	Poisson
Price	-0.0654***	-0.0489***	-0.1337*	-0.1651***	-0.0691	0.0287	-0.0128	-0.0550**	-0.4096***	-0.0916**
	(0.0147)	(0.0131)	(0.0708)	(0.0521)	(0.0773)	(0.0347)	(0.0390)	(0.0232)	(0.0401)	(0.0453)
Wind	-0.0005***	-0.0004***	-0.0010*	-0.0016***	-0.0003	0.0003	0.0001	-0.0004***	-0.0029***	-0.0006*
	(0.0001)	(0.0001)	(0.0005)	(0.0004)	(0.0006)	(0.0002)	(0.0004)	(0.0002)	(0.0004)	(0.0004)
Solar	-0.0004***	-0.0003**	-0.0017*	-0.0012**	0.0001	0.0004	-0.0006	-0.0005**	-0.0025***	-0.0006
	(0.0002)	(0.0002)	(0.0010)	(0.0005)	(0.0009)	(0.0003)	(0.0004)	(0.0002)	(0.0005)	(0.0005)
Load	0.0000***	0.0000**	0.0001	0.0002**	-0.0002*	-0.0001***	0.0000	0.0000*	0.0004***	0.0002***
	(0.0000)	(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Rivers: Low levels	0.3621***	0.2639***	0.3323	0.0568	0.7726**	0.3581**	0.9291	0.1803	0.4998	-0.2116
	(0.1364)	(0.0932)	(0.3991)	(0.8436)	(0.3046)	(0.1683)	(0.5748)	(0.1694)	(0.6186)	(0.4273)
Rivers: High Temp.	-0.0170	-0.0341	0.5189	1.6066***	0.5393**	0.4068***	-3.2738***	-17.2466***	-1.7242***	-1.8081***
	(0.0940)	(0.1155)	(0.6691)	(0.4798)	(0.2284)	(0.1356)	(0.5848)	(0.5696)	(0.3932)	(0.6602)
Constant	6.9911***	7.4979***	0.9637	-14.1093***	13.2264***	9.3670***	3.0567**	6.4173***	-1.4414	0.8187
	(0.7808)	(0.4644)	(1.4335)	(3.0323)	(3.8044)	(0.9594)	(1.2864)	(0.9798)	(1.9031)	(1.0927)
First Stage F stat.	66.49	66.49	66.49	66.49	66.49	66.49	66.49	66.49	66.49	66.49
Critical values (10%)	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08
Hansen J stat.	0.79	-	0.28	-	0.19	-	0.97	-	0.23	-
#Obs.	455	455	455	455	455	455	455	455	455	455

*Notes: Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses robust to heteroscedasticity and autocorrelation. Autocorrelation considered through Newey-West standard errors in GMM models and clustered monthly for Poisson models. Critical values are obtained from Stock and Yogo (2005). Hansen J stat for overidentifying restrictions has the null hypothesis that instruments are orthogonal to the error term. Dependent variables reflect non-usable megawatts per day. River variables are dummies reflecting extraordinary high water temperatures and low water levels. Price variable is the daily average spot prices at the European Power Exchange (EPEX); instruments for the first stage regression of price are hard coal price, gas price and carbon emission right price. Dummies for day of the week and months are included but not reported. All variables are on a daily basis.*

Table 3: Strategic Failures (Unannounced failures with lead time< 1 day; as actually observed)

	All Fuels		*Nuclear*		*Lignite*		*Hard Coal*		*Gas*	
	GMM	Poisson	GMM	Poisson	GMM	Poisson	GMM	Poisson	GMM	Poisson
Price	0.0639*	0.1233***	0.0139**	0.1053	-0.0277	-0.0789	0.0604***	0.1502***	0.0015	0.2016*
	(0.0367)	(0.0377)	(0.0062)	(0.1370)	(0.0228)	(0.0893)	(0.0216)	(0.0454)	(0.0137)	(0.1168)
Wind	0.0006**	0.0009***	0.0001*	0.0005	-0.0001	0.0000	0.0005***	0.0011***	-0.0000	0.0016*
	(0.0003)	(0.0003)	(0.0000)	(0.0012)	(0.0002)	(0.0007)	(0.0002)	(0.0003)	(0.0001)	(0.0009)
Solar	-0.0010*	0.0000	-0.0000	-0.0021	-0.0000	0.0007	-0.0009**	-0.0005	-0.0001	0.0013
	(0.0006)	(0.0004)	(0.0001)	(0.0019)	(0.0003)	(0.0011)	(0.0004)	(0.0007)	(0.0002)	(0.0015)
Load	-0.0001*	-0.0001***	-0.0000***	-0.0001	0.0000	0.0001	-0.0000*	-0.0001***	0.0000	-0.0001
	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0001)
Rivers: Low levels	0.2532	-0.2613	-0.0106	-11.7961***	0.1539	0.0302	0.2492	-0.7201**	-0.1598	-14.7621***
	(0.3104)	(0.3618)	(0.0405)	(0.7939)	(0.1701)	(0.7290)	(0.1862)	(0.3639)	(0.1213)	(0.5916)
Rivers: High Temp.	2.5286***	0.9788***	-0.0042	-0.8728	0.0411	0.3494	1.9882***	0.7694*	-0.0116	-1.5280**
	(0.5426)	(0.3477)	(0.0329)	(0.7016)	(0.2263)	(0.8554)	(0.5354)	(0.4090)	(0.0474)	(0.6394)
Constant	1.4432	3.4478***	0.2384	-14.4748***	-0.2841	-13.3994***	-0.0432	1.7754	-0.4585	-2.1290
	(2.1099)	(0.9263)	(0.2143)	(4.0478)	(0.7607)	(3.9561)	(1.0663)	(1.4030)	(0.4174)	(3.1133)
First Stage F stat.	66.49	66.49	66.49	66.49	66.49	66.49	66.49	66.49	66.49	66.49
Critical values (10%)	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08
Hansen J stat.	0.84	-	0.18	-	0.20	-	0.92	-	0.33	-
#Obs.	455	455	455	455	455	455	455	455	455	455

*Notes: Significance levels: * p < 0.1, ** p < 0.05, *** p < 0.01. Standard errors in parentheses robust to heteroskedasticit and autocorrelationy. Autocorrelation considered through Newey-West standard errors in GMM models and clustered monthly for Poisson models. Critical values are obtained from Stock and Yogo (2005). Hansen J stat for overidentifying restrictions has the null hypothesis that instruments are orthogonal to the error term. Dependent variables reflect non-usable megawatts per day. River variables are dummies reflecting extraordinary high water temperatures and low water levels. Price variable is the daily average spot prices at the European Power Exchange (EPEX); instruments for the first stage regression of price are hard coal price, gas price and carbon emission right prices. Dummies for day of the week and months are included but not reported. All variables are on a daily basis.*

Semiparametric estimation approach

We now investigate the robustness of our previous findings against a non-linear specification of the price impact on failures. We therefore estimate a semiparametric partially linear regression model with Robinson's (1988) double residual method. Consider a partially linear regression model of the type

$$Failure = \theta_0 + X\theta + f(P) + \varepsilon \quad (4)$$

where X is the row vector of control variables, and θ_0 is the intercept term. Variable P represents price and enters the equation non-linearly according to a non-binding function *f*. ε is the disturbance, assumed to have $E(\varepsilon|P) = 0$, an assumption which we will later relax. The double residual methodology applies conditional expectation on both sides leading to

$$E(Failure|P) = \theta_0 + E(X|P)\theta + f(P) \quad (5)$$

and through subtracting equation (5) from equation (4), we get

$$Failure - E(Failure|P) = \big(X - E(X|P)\big)\theta + \varepsilon \quad (6)$$

where $Failure - E(Failure|P) = \varepsilon_1$ and $X - E(X|P) = \varepsilon_2$ reflect the two residuals. In a two-step procedure we first obtain estimates of the conditional expectations $E_n(Failure|P)$ and $E_n(X|P)$ from some non-parametric (kernel) estimations of the form $Failure = m_{Failure}(P) + \varepsilon_1$ and $Z_{ki} = m_{X_k}(P) + \varepsilon_2$ with *k=1,..,K* indexing the control variables entering the model parametrically. After inserting the estimated conditional expectations in equation (6), Robinson's method enables us to estimate the parameter vector θ consistently without explicitly modelling $f(\mathrm{P})$ by a standard non-intercept OLS regression and we obtain $\hat{\theta} = (\hat{\varepsilon}_2'\hat{\varepsilon}_2)^{-1}(\hat{\varepsilon}_2'\hat{\varepsilon}_1)$. Finally, $f(P)$ is estimated by regressing $\big(Failure - X\hat{\theta}\big)$ on P non-parametrically.

The endogenous nature of the non-parametrically modelled variable P, however, yields $E(\varepsilon|P) \neq 0$. As standard IV-techniques such as 2-SLS and IV GMM yield biased estimates for non-linear models, we apply a two-stage residual inclusion approach (2SRI) by plugging the residuals ν_1 from the first-stage estimation of P from equation (1) as control function into the semi-parametric regression model in equation (6) (see Blundell and Powell, 2004 and Imbens and Wooldridge, 2009, respectively). The results from the semi-parametric regressions are illustrated in Figure 2 and Table 4 below.

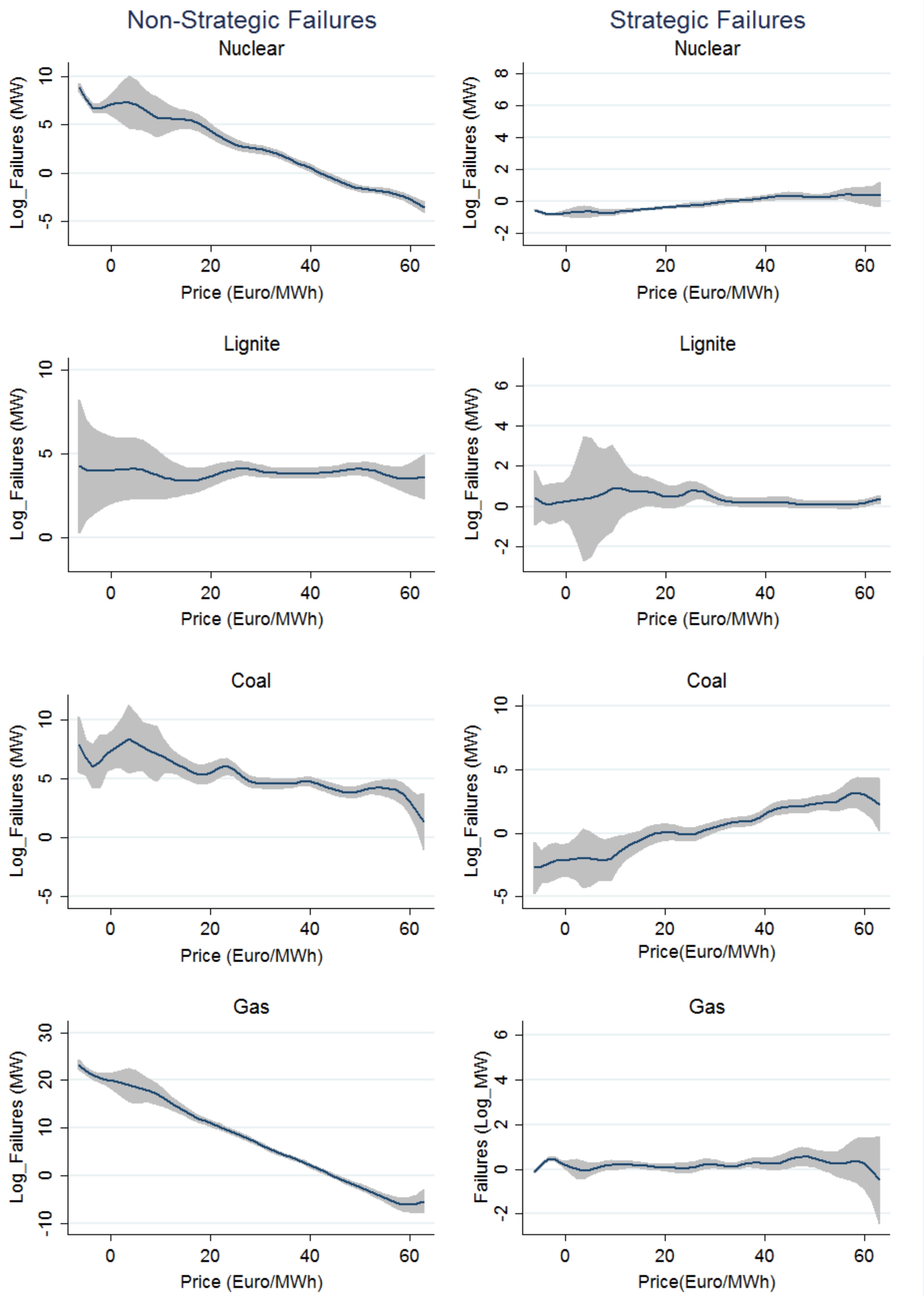

Figure 2: Non-parametric Fit from Semiparametric Control Function Regression

Notes: Illustration of non-linear relation between failures and price with the grey areas delineating the respective 95 percent confidence intervals. Estimated by Robinsons's (1989) semiparametric double residual method. Endogeneity considered through a two-stage residual inclusion approach with the residuals from the first stage estimation of price in equation (1) as control function for endogeneity.

Table 4: Semi-parametric Estimates of the Impact of Price on Failures

	Non-strategic Failures					Strategic Failures				
	All Fuels	*Nuclear*	*Lignite*	*Hard Coal*	*Gas*	*All Fuels*	*Nuclear*	*Lignite*	*Hard Coal*	*Gas*
Price	Non-parametric	Non-parametric	Non-parametric	Non-parametric	Non-parametric	Non-parametric	Non-parametric	Non-parametric	Non-parametric	Non-parametric
Wind	-0.0005***	-0.0015**	-0.0003	-0.0001	-0.0026***	0.0008*	0.0001	0.0001	0.0006*	0.0000
	(0.0002)	(0.0006)	(0.0006)	(0.0004)	(0.0006)	(0.0004)	(0.0001)	(0.0002)	(0.0003)	(0.0002)
Solar	-0.0005**	-0.0020**	0.0005	-0.0006	-0.0022***	-0.0006	-0.0001	0.0001	-0.0008	0.0000
	(0.0002)	(0.0009)	(0.0009)	(0.0006)	(0.0007)	(0.0007)	(0.0002)	(0.0003)	(0.0006)	(0.0003)
Load	0.0001**	0.0001**	-0.0001	0.0001	0.0004***	-0.0001*	-0.0000	0.0000	-0.0001	0.0000
	(0.0000)	(0.0001)	(0.0001)	(0.0000)	(0.0001)	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Rivers: Low levels	0.3577**	0.4726	0.3808	0.8407	0.3653	0.2489	0.0096	0.1535	0.2550	-0.1769
	(0.1492)	(0.7511)	(0.4891)	(0.7348)	(0.7994)	(0.5548)	(0.0886)	(0.2760)	(0.4829)	(0.1550)
Rivers: High Temp.	-0.0287	0.9394	0.2476	-3.4122	-1.8574	2.5952***	-0.0072	0.0191	2.0526***	-0.0528
	(0.2060)	(1.2994)	(0.5314)	(2.1095)	(1.4390)	(0.9295)	(0.0993)	(0.3691)	(0.7674)	(0.1519)
Control Function	0.0411*	0.1151	-0.0188	0.0134	0.2928***	0.0118	0.0036	0.0094	0.0019	0.0083
	(0.0239)	(0.0901)	(0.0835)	(0.0561)	(0.0824)	(0.0607)	(0.0178)	(0.0398)	(0.0499)	(0.0264)
First Stage F stat.	16.08	16.08	16.08	16.08	16.08	16.08	16.08	16.08	16.08	16.08
Critical values (10%)	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08	9.08
#Obs.	455	455	455	455	455	455	455	455	455	455

Notes: Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses. Block bootstrap S.E. on weekly blocks. Estimation by the Robinson (1988) double residual estimator with price modelled non-parametrically. Critical values are obtained from Stock and Yogo (2005). Price variable is the daily average spot prices at the European Power Exchange (EPEX). Endogeneity of price considered through a two-stage residual inclusion approach with the residuals from the reduced form estimation of *Price* (Equation 1) as control function; instruments for the first stage regression of price are hard coal price, gas price and carbon emission right price. Dependent variables reflect non-usable megawatts per day. River variables are dummies reflecting extraordinary high water temperatures and low water levels. Dummies for day of the week and months are included but not reported. All variables are on a daily basis.

Confirming our earlier results of the parametric estimation approach, we again find the negative relationship between non-strategic failures and price throughout all fuels besides lignite. For the strategic failures, the only fuel type showing a positive relationship is again hard coal allowing the final conclusion that our empirical analysis finds evidence consistent with the presence of capacity withholding strategies in the German-Austrian electricity market during our observation period from 1 January 2013 to 31 March 2014.

5 Conclusion

In the integrated German-Austrian electricity market, a substantial fraction of electricity is traded on the day-ahead auction market – the EPEX Spot – via uniform price auctions. An important general characteristic of such auctions is that all operators receive the same price (per unit of output) which is determined by the costs of the marginal plant that is just needed to satisfy demand.

In such an environment, the capacity withholding strategy makes use of the fact that the supply schedule typically is convex while demand is unresponsive to price signals in the short-term. Hence, whenever demand is high, a small reduction in supply substantially increases the marginal price and the price all operators receive. By strategically removing a fraction of their operating capacity from the market (e.g., by pretending a sudden failure of a generation unit), multi-unit plant operators expect that the correspondingly higher prices realized for the remaining operating units offset the lost revenues from the (strategically) removed capacity and thus lead to a net increase in profits.

In this context, we have investigated whether prices in the German-Austrian electricity market are found to have a significant influence on the capacity that is non-usable on a specific day. Differentiating between announced ‘non-strategic’ and unannounced (spontaneous) ‘strategic’ failures and applying parametric as well as semiparametric estimation methods, we find evidence consistent with the hypothesis of the presence of strategic capacity withholding activities in the German-Austrian electricity market during our observation period from 1 January 2013 to 31 March 2014. In particular, we consistently find a significantly positive influence of prices on non-usable megawatts of hard coal-fueled (and partly also gas-fueled) plants as marginal technologies for the case of *strategic* failures only. In contrast, we find a negative impact of price for *non-strategic* failures reflecting maintenance activities.

Our empirical evidence raises the question after policy implications. As the possibility of capacity withholding is closely connected to the mechanics of the uniform price auction, an obvious suggestion would be to consider switching to an alternative market design such as pay-as-bid-auctions. However, independent of an answer to the question whether the problem of capacity withholding would indeed be solved by such a switch (see, e.g., Cramton and Stoft, 2007, Heim and Götz, 2013, or Kahn et al., 2001), the choice of a certain market design is certainly determined by a careful evaluation of a multitude of different factors with the possibilities for strategic capacity withholding being only one criterion.[28]

This raises the question how the likelihood of the occurrence of such strategies can be reduced within the currently implemented regime. In addition to a possible introduction of a system of price caps together with additional capacity payments or the promotion of demand side participation in order to increase demand elasticity, it appears particularly important for the responsible authorities to urge market participants to report more detailed information about power plant non-usabilities in order to ease and improve monitoring efforts. However, although such increased monitoring efforts might reduce the likelihood of capacity withholding strategies, the probability that an operator will eventually be fined for strategic capacity withholding under current competition laws in Germany and Europe is rather low – and only appears possible if different types of empirical evidence are complemented by clear written evidence that such behavior has actually (and willfully) been applied in the German-Austrian electricity market.

References

Becker, P. (2008), Kartellrechtliche Kontrolle von Strompreisen, Zeitschrift für Neues Energierecht 12/4/2008, 289-297.

Blundell, R. and J. Powell (2004), Endogeneity in Semiparametric Binary Response Models, Review of Economic Studies 71, 581–913.

Cabral, L. (2002), The California Energy Crisis, Japan and the World Economy 14 (3), 335-339.

Carlton, D. and J. Perloff (2000), Modern Industrial Organization, Reading.

Cramton, P. and S. Stoft (2007), Why We Need to Stick with Uniform-Price Auctions in Electricity Markets, Electricity Journal 20 (1), 26-37.

[28] However, interestingly, the belief that uniform auctions are more subject to strategic manipulation by larger traders than pay-as-bid auctions was one of the main reasons for the 2001 New Electricity Trading Arrangement (NETA) market design reform in England and Wales as part of which the British regulator OFGEM decided to switch from uniform price auctions to pay-as-bid auctions.

Dämon, K. (2011), Stromkonzerne sollen Preise manipuliert haben, WirtschaftsWoche 7th November 2011, available at: http://www.wiwo.de/politik/deutschland/energiemarkt-stromkonzerne-sollen-preise-manipuliert-haben/5809056-all.html (last accessed on 8 January 2016).

Dechenaux, E. and D. Kovenock (2007), Tacit Collusion and Capacity Withholding in Repeated Uniform Price Auctions, RAND Journal of Economics 38 (4), 1044–1069.

Evans, J. and R. Green (2003), Why Did British Electricity Prices Fall after 1998?, Cambridge Working Papers in Economics 0326, University of Cambridge, Cambridge.

Federal Cartel Office (2011), Sector Inquiry into Electricity Generation and Wholesale Markets, Report in Accordance with Section 32e (3) of the German Act against Restraints of Competition-ARC, January 2011, Bonn.

Fogelberg, S. and E. Lazarczyk (2014), Strategic Withholding through Production Failures, IFN Working Paper No. 1015, Stockholm.

Fouquet, D., A. Seidenspinner and J. Füller (2011), Wettbewerbs- und Energiepolitsche Lücken der Sektoruntersuchung “Stromerzeugung, Stromgroßhandel” des Bundeskartellamts vom Januar 2011, Kurzgutachten im Auftrag der Bundestagsfraktion der Partei Bündnis 90/Die Grünen, München.

Heim, S. and G. Götz (2013), Do Pay-as-bid Auctions Favor Collusion? Evidence from Germany's Market for Reserve Power, ZEW Discussion Paper No. 13-035, Mannheim.

Imbens, G. and J. Wooldridge (2009), Recent Developments in the Econometrics of Program Evaluation, Journal of Economic Literature 47, 5-86.

Jahn, M. (2008), Zur Strafbarkeit von Manipulationen des Handels an der Strombörse EEX in Leipzig, Zeitschrift für Neues Energierecht 12/4/2008, 297-314.

Joskow, P. and E. Kahn (2002), A Quantitative Analysis of Pricing Behavior in California’s Wholesale Electricity Market During Summer 2000, Energy Journal 23 (4), 1-36

Jungbluth, C. and J. Borchert (2008), Möglichkeiten der Strompreisbeeinflussung im oligopolistischen Markt, Zeitschrift für Neues Energierecht 12/4/2008, 314-323.

Kahn, A., P. Cramton, R. Porter and R. Tabors (2001), Uniform Pricing or Pay-as-Bid Pricing: A Dilemma for California and Beyond, The Electricity Journal 14 (6), 70-79.

Kumar, N., P. Besuner, S. Lefton, D. Agan and D. Hilleman (2012), Power Plant Cycling Costs, Intertek APTECH, NREL Technical Monitor, Sunnyvale.

Kwoka, J. and V. Sabodash (2011), Price Spikes in Energy Markets: “Business by Usual Methods” or Strategic Withholding, Review of Industrial Organization 38 (3), 285-310.

Lefton, S., P. Besuner and G. Grimsrud (1995), Managing Utility Power Plant Assets to Economically Optimize Power Plant Cycling Costs, Life, and Reliability, Proceedings of the 4th IEEE Conference on Control Applications, available at: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=555681 (last accessed on 8 January 2016).

McDermott, G. and Ø. Nilsen (2012), Electricity Prices, River Temperatures and Cooling Water Scarcity, IZA Discussion Paper No. 6842, Bonn.

Müsgens, F. (2006), Quantifiying Market Power in the German Wholesale Electricity Market Using a Dynamic Multi-Regional Dispatch Model, Journal of Industrial Economics 54, 471-498.

Newbery, D. (1995), Power Markets and Market Power, Energy Journal 16 (3), 39-66.

Robinson, P. (1988), Root-N-Consistent Semiparametric Regression, Econometrica 56, 931-954.

Schumann, D. (2009), E.ON soll Strombörse manipuliert haben. Zeit Online, 31th July 2009, available at http://www.zeit.de/online/2009/11/energiemarkt-eon-boerse (last accessed on 8 January 2016).

Schwarz, H.-G. and C. Lang (2006), The Rise in German Wholesale Electricity Prices: Fundamental Factors, Exercise of Market Power, or Both? IWE Working Paper Nr. 02, University of Erlangen-Nuremberg.

Silva, S. and S. Tenreyro (2011), Poisson: Some Convergence Issues, Stata Journal 11(2), 215-225.

Stock, J. and M. Yogo (2005), Testing for weak instruments in linear IV regression, in: D. Andrews and H. Stock, Identification and Inference for Econometric Models: Essays in Honor of Thomas Rothenberg, 80-108.

Stoft, S. (2002), Power System Economics - Designing Markets for Electricity, New York.

Swider, D., I. Ellersdorfer, M. Hundt and A. Voß (2007), Herausforderungen beim empirischen Nachweis von Marktmacht am deutschen Elektrizitätsmarkt, Bericht zu den Ergebnissen eines Gutachtens im Auftrag des VRE Verband der Verbundunternehmen und Regionalen Energieversorger in Deutschland, IER-Info Presentation, 24 May 2007, Stuttgart.

Von Hirschhausen, C., H. Weigt and G. Zachmann (2007), Preisbildung und Marktmacht auf den Elektrizitätsmärkten in Deutschland: Grundlegende Mechanismen und empirische Evidenz, Gutachten im Auftrag des VIK Verband der Industriellen Energie- und Kraftwirtschaft, Dresden.

Wolak, F. and R. Patrick (2001), The Impact of Market Rules and Market Structure on the Price Determination Process in the England and Wales Electricity Market, NBER Working Paper No. 8248, Cambridge.

Wolfram, C. (1998), Strategic Bidding in a Multiunit Auction: An Empirical Analysis of Bids to Supply Electricity in England and Wales, RAND Journal of Economics 29 (4), 703-725.